VNIVERSITAT DE VALÈNCIA Facultat de Magisteri

Natural sciences for schoolteachers
LESSON 6:
Biodiversity

Contents

1. The cell.
2. Organisms.
3. Ecosystems.
4. Origin and evolution of organisms.

The cell

All known living organisms are composed of basic units called **cells**.

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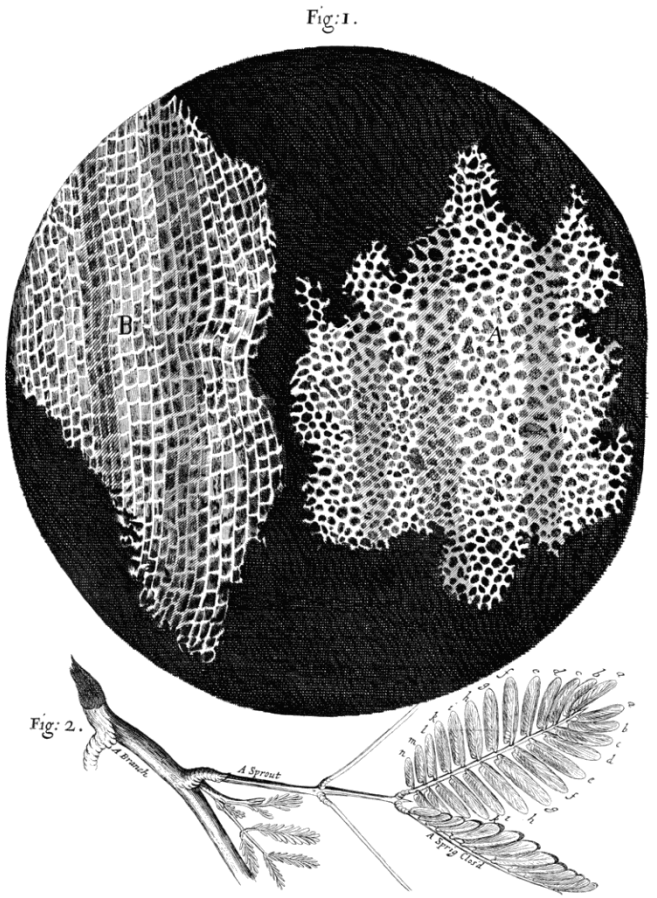
The cell

Cell theory

In 1665, **Robert Hooke** (1635–1703) observed a very thin slice of cork under a microscope and discovered that it consisted of a multitude of empty spaces contained by walls.

Hooke named these spaces **cells** because they resembled the small rooms inhabited by monks (from Latin *"cella"*, meaning small room).

However, Hooke only was able to observe dead cells, so he could not describe the structures within.



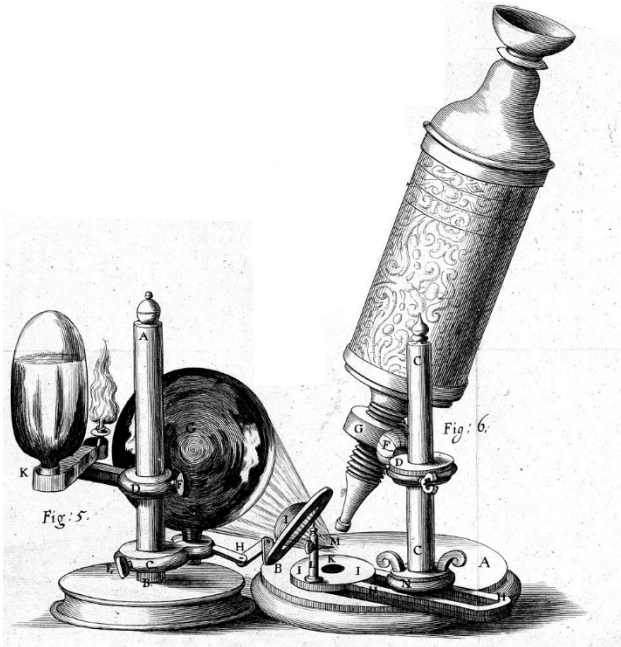
The cell

Cell theory

Antonie van Leeuwenhoek (1632–1723) made a microscope in 1674 that allowed him to observe muscular fibers, protozoa, bacteria, spermatozoa and red blood cells.

In the 1830s, **Theodor Schwann** (1810–1882) and **Matthias Jakob Schleiden** (1804–1881) stated that ***plants and animals are composed of cells***.

In 1855, **Rudolf Virchow** (1821–1902) stated that ***new cells come from pre-existing cells***.



The cell

Cell theory

The four main principles of the **cell theory** are:

1. ***All living organisms are composed of one or more cells.*** The cell is the basic unit of structure and organization in organisms.
2. ***The cell is the most basic unit of life.*** The cell is the basic unit of function in organisms, since the activity of an organism depends on the total activity of independent cells (nutrition, relationship and reproduction).
3. ***Cells come from pre-existing cells.***
4. ***Cells contain all the information about their structure and function and are capable of transmitting it to their daughters.***

Therefore, ***cells are the basic unit of structure, function and reproduction of all living organisms.***

The cell

Prokaryotic and eukaryotic cells

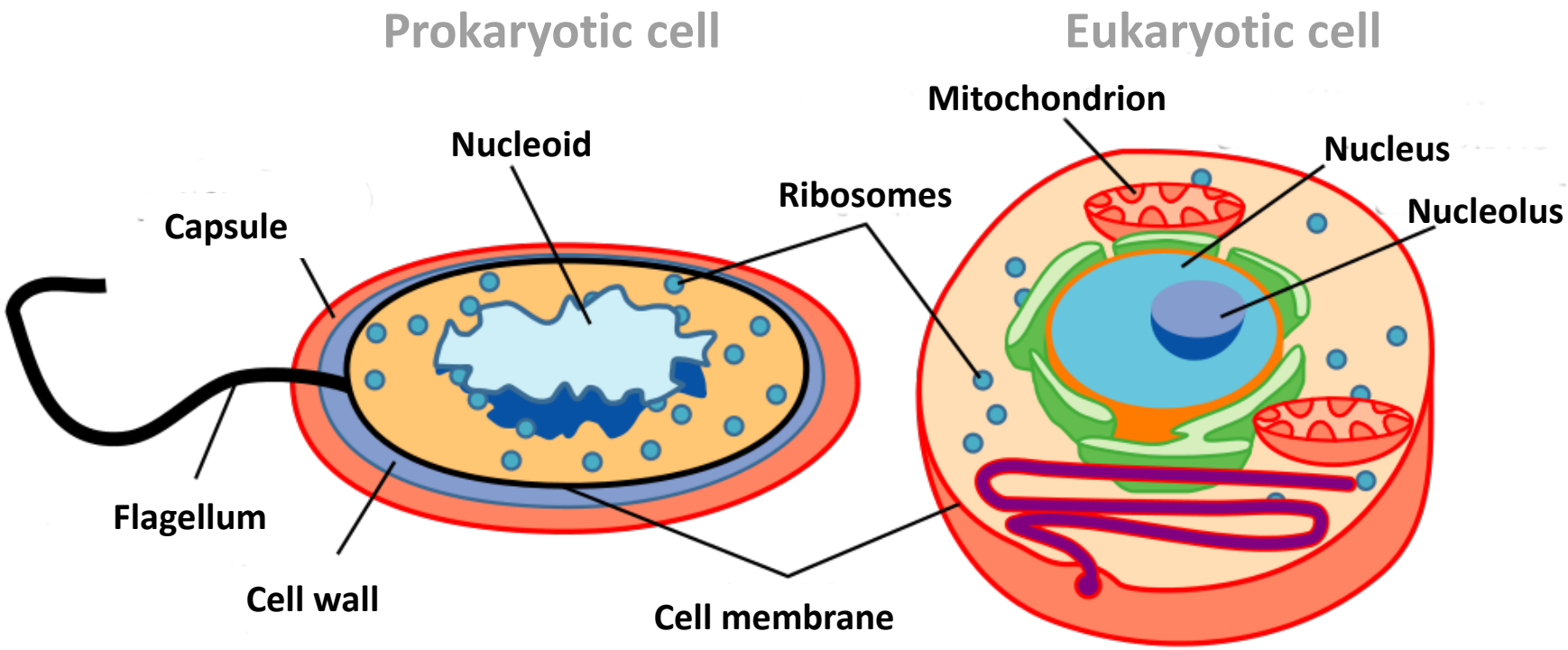
The cells that compose a living organism are very similar:

- ✓ All cells have a **membrane** that separates their interior from the outside environment.
- ✓ The membrane encloses a material called **cytoplasm**, which contains the cell's internal sub-structures and genetic material.

Depending on their complexity, cells are of two types: **prokaryotic** and **eukaryotic**.

The cell

Prokaryotic and eukaryotic cells



The cell

Prokaryotic and eukaryotic cells

Prokaryotic cells are the simplest cells.

They consist of ***cytoplasm*** enclosed within a ***membrane***.

Surrounding the cell, just outside the cell membrane, there is a ***cell wall*** which provides the cell with both structural support and protection.

The ***genetic material*** is spread throughout the cytoplasm of the entire cell. The only organelles they possess are ***ribosomes***.

Bacteria are prokaryotes.

The cell

Prokaryotic and eukaryotic cells

Eukaryotic cells consist of ***cytoplasm*** enclosed within a ***membrane***. They rarely have a cell wall.

There are structures within the cytoplasm called ***organelles***, which have specific functions that are vital for the cell to live.

The ***genetic material*** is enclosed by two membranes that isolate it from the cytoplasm. This forms the cell ***nucleus***, which controls the activities of the cell.

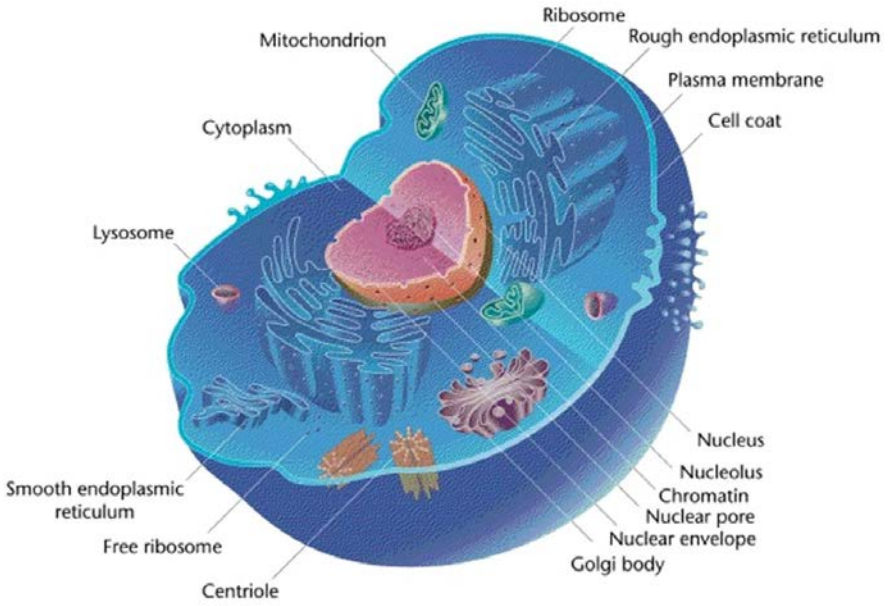
Protozoa, fungi, plants and animals are eukaryotes.

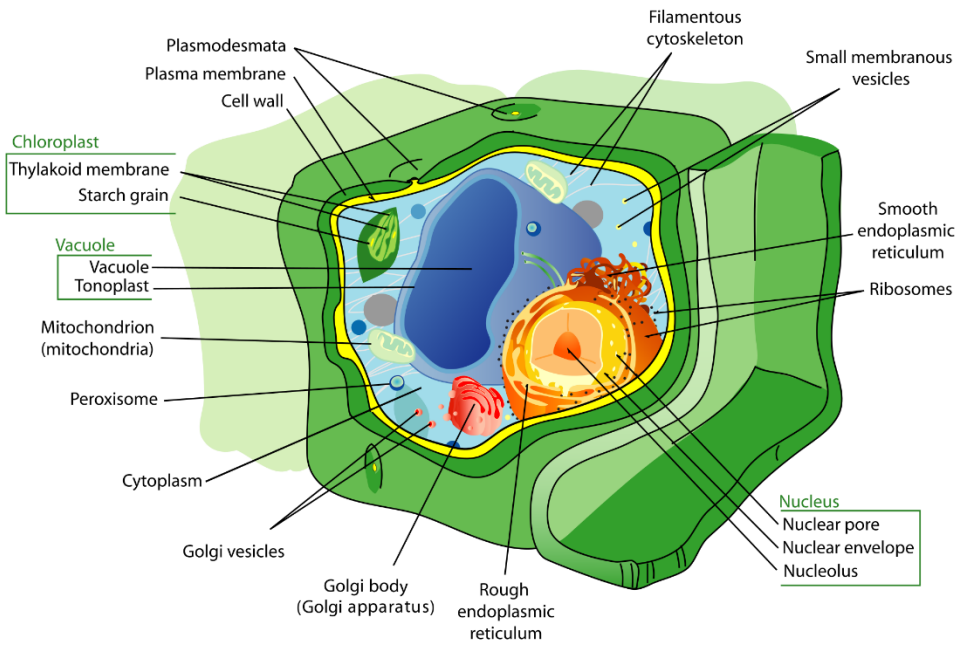
The cell

Structure of a eukaryotic cell

There are two main types of **eukaryotic cells**: ***animal*** and ***plant*** cells.

Eukaryotic cells consist of three different parts: the ***cell membrane***, the ***cytoplasm*** and the ***nucleus***.





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The cell

Structure of a eukaryotic cell

ANIMAL CELL	PLANT CELL
cell membrane	
-----	cell wall
cytoplasm	
ribosomes	
endoplasmic reticulum	
Golgi apparatus	
lysosomes	-----
vacuoles (sometimes, small & plenty)	vacuoles (2 or 3, big)
mitochondrias	
-----	chloroplasts
centrosome	-----
nucleus	

The cell

Structure of a eukaryotic cell: cell membrane

The **cell membrane** (a.k.a. ***plasma membrane***) is a barrier that encloses the cell, and is mainly composed of lipids, proteins and carbohydrates.

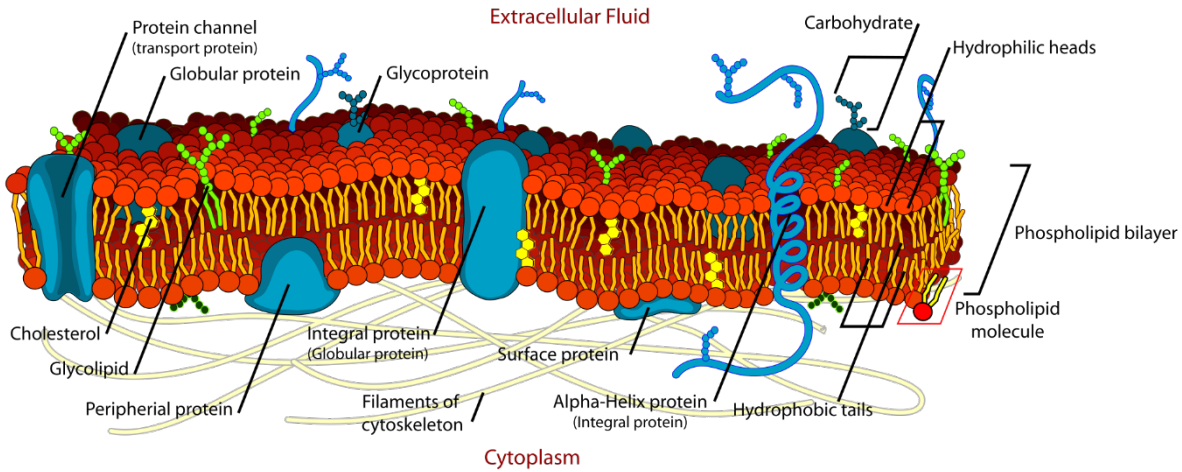


Image: LadyofHats

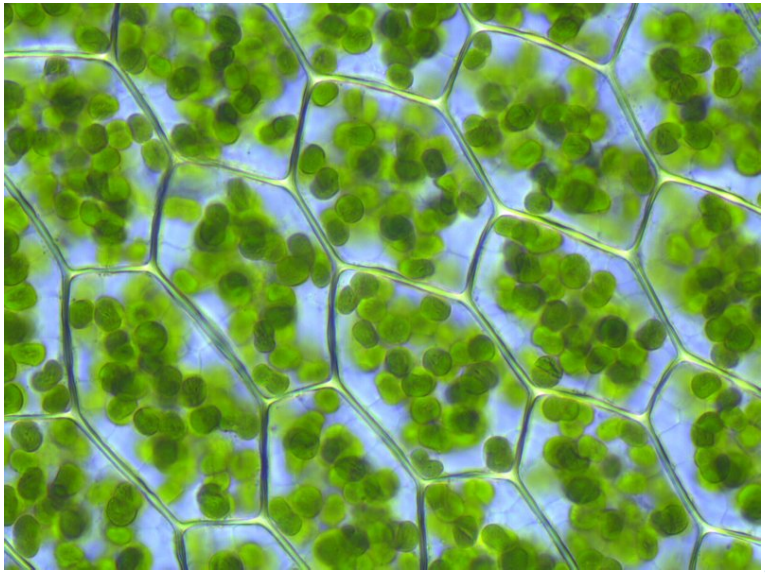
The basic functions of the cell membrane are:

- ✓ ***to protect the cell from its surroundings***, separating the interior of the cell from the outside environment.
- ✓ ***to control the movement of substances in and out of cells and organelles***.

The cell

Structure of a eukaryotic cell: cell wall

Plant cells have a tough and flexible layer surrounding them called **cell wall**, just outside the cell membrane. It is mainly composed of ***cellulose***.



It provides the cell with both ***structural support*** and ***protection***.

The cell

Structure of a eukaryotic cell: cytoplasm

The **cytoplasm** is the material within a living cell, excluding the cell nucleus. The three major elements of the cytoplasm are:

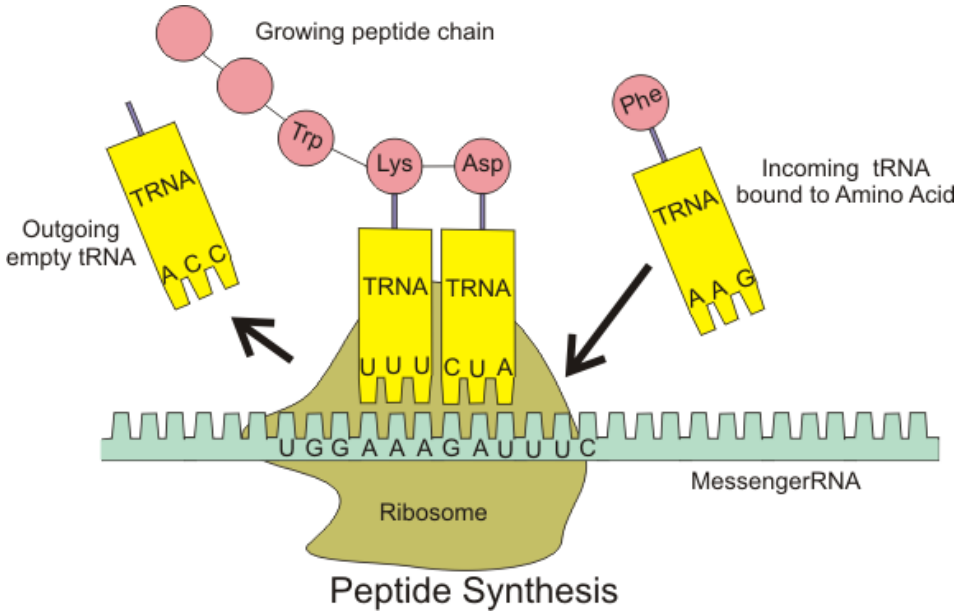
- ✓ The ***cytosol***, which is the gel-like substance enclosed within the cell membrane. It is a complex mixture of substances (proteins, lipids, carbohydrates and mineral salts) dissolved in water. Multiple cell processes take place in the cytosol.
- ✓ The ***organelles***, which are structures inside the cell that have specific functions.
- ✓ The ***cytoskeleton***, which is a complex network of interlinking filaments and tubules that extend throughout the cytoplasm. Its primary function is to give the cell its shape and mechanical resistance to deformation. It is also involved in intracellular transport.

The cell

Structure of a eukaryotic cell: ribosomes

Ribosomes are tiny granules made of ribonucleic acid (RNA) and proteins. They can be found floating within the cytoplasm or attached to the endoplasmic reticulum.

The main function of ribosomes is ***to synthesize proteins***, which are needed for many cellular functions.



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The cell

Structure of a eukaryotic cell: endoplasmic reticulum

The **endoplasmic reticulum** is a network of membranes that are continuous with the outer nuclear membrane.

There are two types of endoplasmic reticulum:

- ✓ ***rough*** (its outer face is studded with ribosomes)
- ✓ ***smooth*** (it lacks ribosomes)

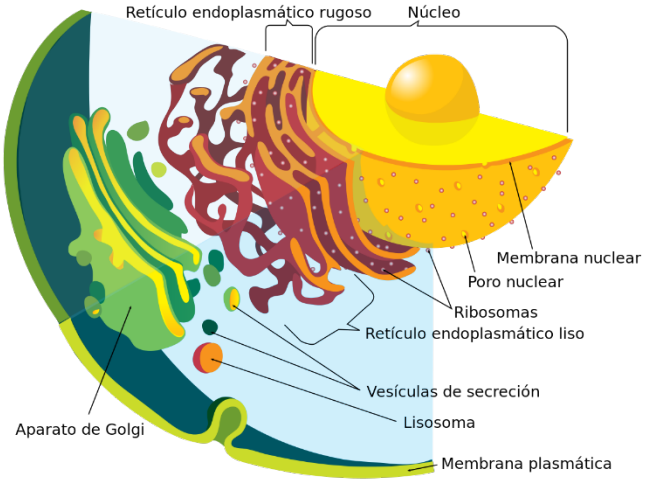


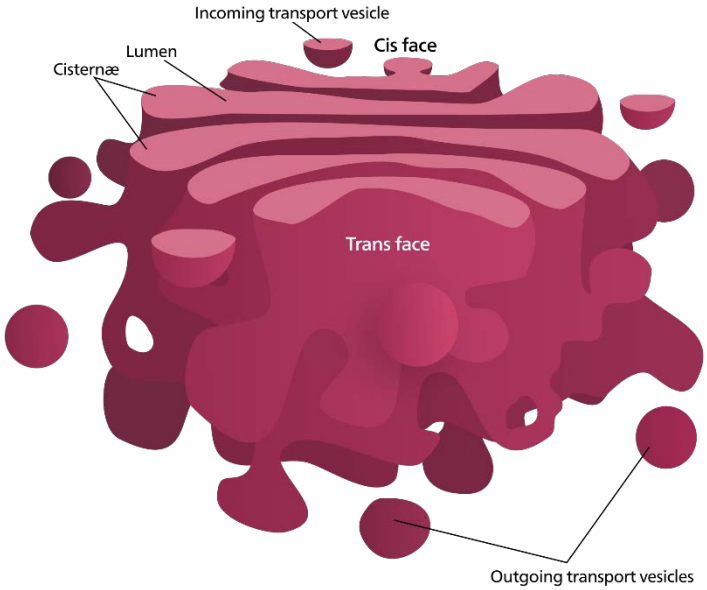
Image: LadyofHats

It transports the proteins synthesized by the ribosomes to the Golgi apparatus. It also synthesizes lipids.

The cell

Structure of a eukaryotic cell: Golgi apparatus

The **Golgi apparatus** is a collection of fused, flattened disks from which proteins are packaged into vesicles. It is usually located near the cell nucleus.



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It packages the proteins received from the endoplasmic reticulum into vesicles before sending them to different parts of the cell or the extracellular space.

Structure of a eukaryotic cell: lysosomes

Lysosomes, which are only found in ***animal cells***, are vesicles that contain enzymes synthesized in the rough endoplasmic reticulum that can break down many kinds of biomolecules (proteins, nucleic acids, carbohydrates, and lipids).

Lysosomes function as the ***digestive system of the cell***, serving both to degrade material taken up from outside the cell and to digest obsolete components of the cell itself.

The cell

Structure of a eukaryotic cell: vacuoles

The **vacuoles**, found in every ***plant cell*** and some animal cells, are enclosed compartments filled with water containing inorganic and organic molecules. They are formed by the fusion of multiple vesicles.

They can occupy between 30 - 80% of the cell's volume.

Their main function is to ***storage substances*** (water, molecules, waste products).

The cell

Structure of a eukaryotic cell: mitochondria

Mitochondria are found in the cytoplasm of every cell.

They have a double-membrane structure: the outer membrane, which encloses the entire organelle, and the inner membrane, which has many folds called ***cristae***. The space enclosed by the inner membrane (***matrix***) contains the enzymes that facilitate the reactions responsible for the production of energy.

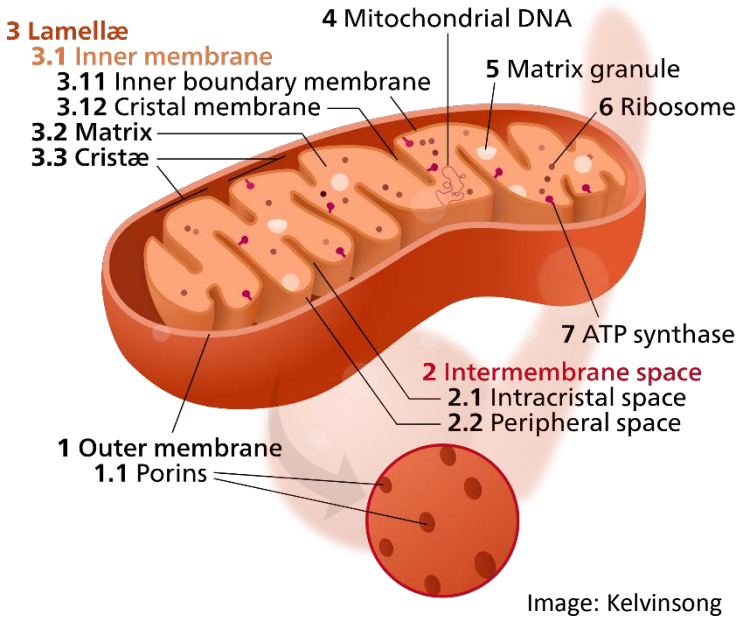

Image: Kelvinsong
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The main function of the mitochondria is ***to provide energy for the cell*** through a set of reactions involved in the ***cellular respiration***.

The cell

Structure of a eukaryotic cell: chloroplast

Chloroplasts are only found in ***plant cells***.

They have two membranes: the outer membrane, which contains and protects the inner parts of the chloroplast, and the inner membrane, which surrounds the ***stroma*** (colorless fluid within the chloroplast) and the ***grana*** (stacks of disks where ***chlorophyll*** is found).

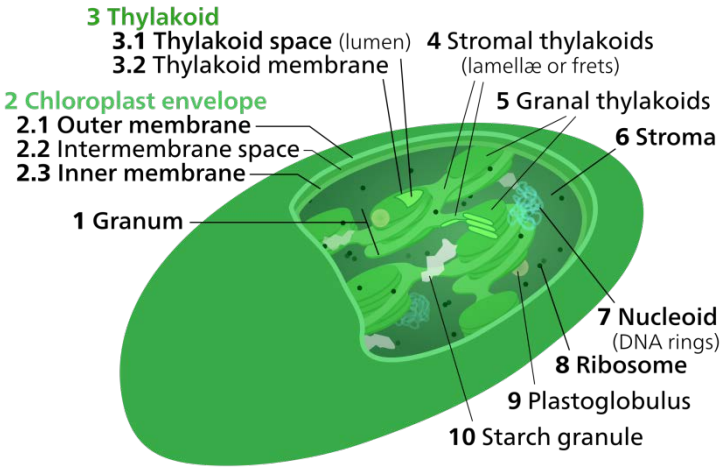

Image: Kelvinsong
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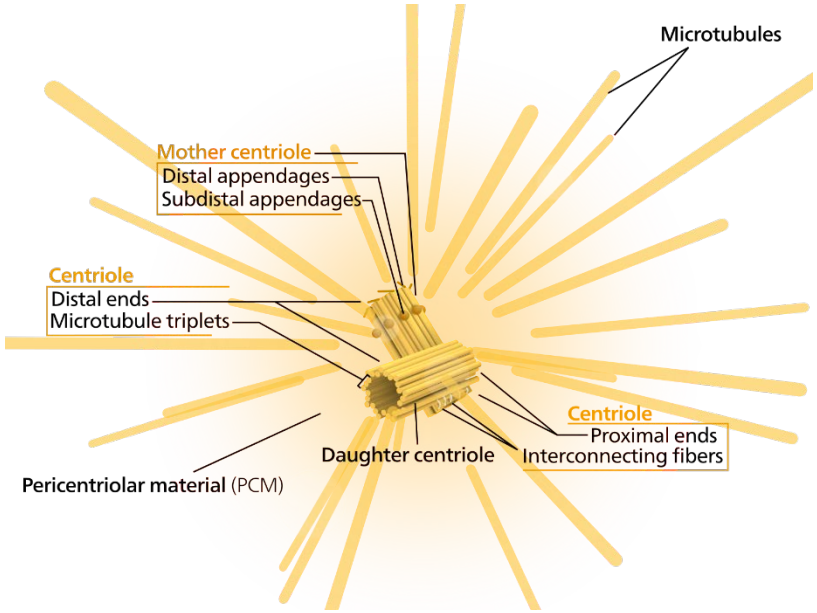
Their main function is to conduct the ***photosynthesis***, where chlorophyll captures and uses the sunlight's energy to synthesize organic matter from inorganic matter (carbohydrates synthesized from carbon dioxide and water). Oxygen is released as a waste product.

The cell

Structure of a eukaryotic cell: centrosome

The **centrosome**, which is only found in ***animal cells***, is composed of two cylindrical structures called ***centrioles***.



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The centrosome has a fundamental role in ***cell division***, separating the genetic material between daughter cells. They also organize the ***flagella*** and ***cilia*** of eukaryotic cells.

The cell

Structure of a eukaryotic cell: cell nucleus

The **cell nucleus** is the characteristic structure of the ***eukaryotic cell***.

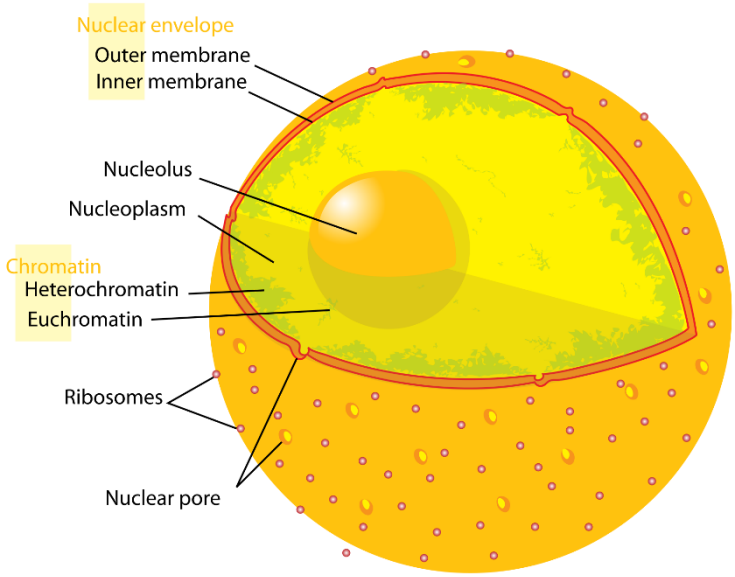


Image: LadyofHats

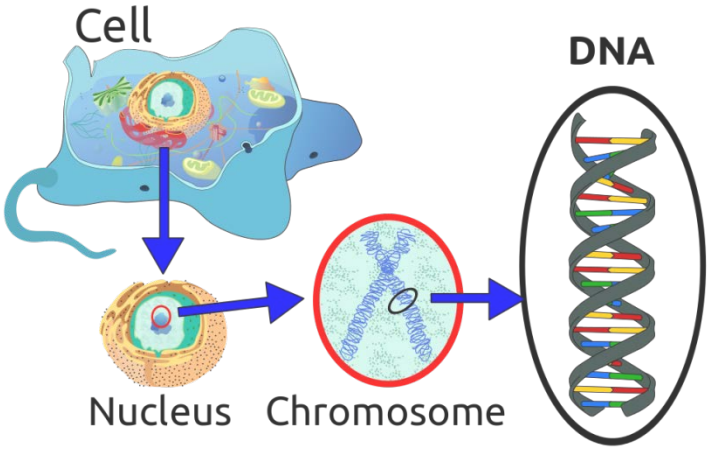
The nucleus consists in a double membrane (***nuclear envelope***) that completely encloses it and separates the cell's genetic material, which is in the form of **deoxyribonucleic acid (DNA)**, from the cytoplasm. The viscous liquid within it is called ***nucleoplasm***, which contains fibers made of DNA molecules (***chromatin***) and structures composed of ribonucleic acid (RNA) (***nucleolus***).

The cell

Structure of a eukaryotic cell: cell nucleus

Chromatin is the substance in the cell nucleus that contains the cell's genetic material. It consists of organized **DNA** molecules.

During cell division, chromatin is packaged into a condensed structure to form **chromosomes**.



Chromosomes contain the ***genetic material*** of an organism. Each sequence of DNA in a chromosome that determines the genetic traits (eye color, blood type, number of limbs, etc.) of an organism is called **gene**.

The cell

Structure of a eukaryotic cell: cell nucleus

The number, shape, and size of chromosomes are ***a characteristic of each species***. All cells of an organism have the same total number of chromosomes.

Image: Piolinfax

Most eukaryotes have ***two homologous copies of each chromosome*** in the cell nucleus, usually one from the mother and one from the father.

The cell

Cell division

Cell division is the process by which a parent cell divides into two or more daughter cells.

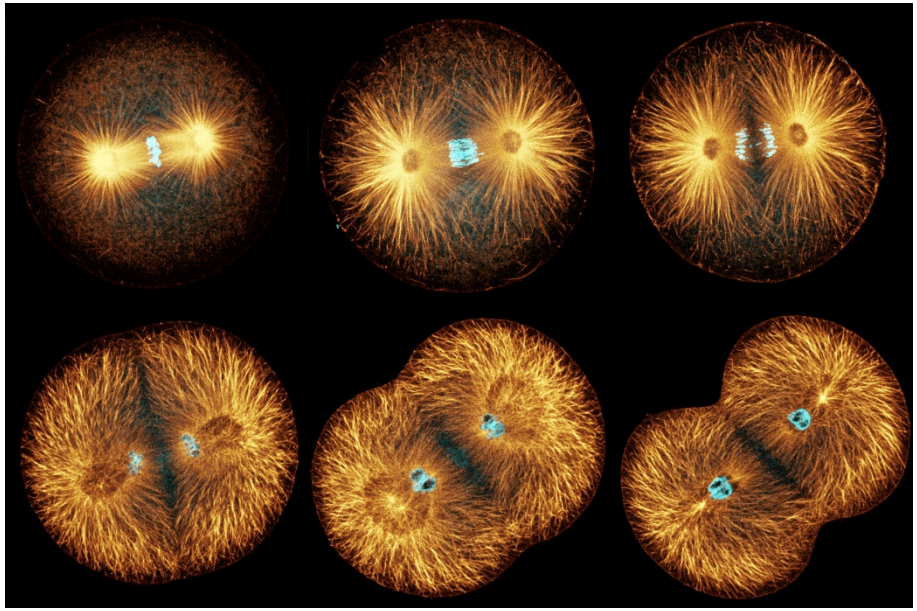


Image: George von Dassow / Victoria Foe / Bill Bement
http://www.celldynamics.org/celldynamics/research/cytokinesis/index.html

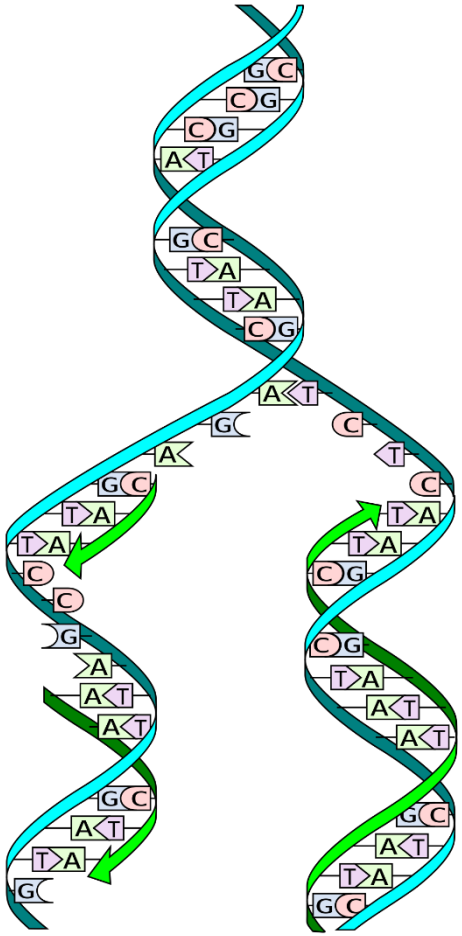
Because of cell division, organisms replace worn-out cells and grow.

The cell

Cell division

Every cell division is preceded by **DNA replication**, which is the process of producing two identical replicas of DNA from one original DNA molecule.

The two strands of the DNA double helix are separated, and each strand of the original DNA molecule acts as a template for replicating its counterpart.



The cell

Cell division: Mitosis

Mitosis is a part of the cell division when ***the replicated genetic material of the parent cell is separated into two new daughter cells***.

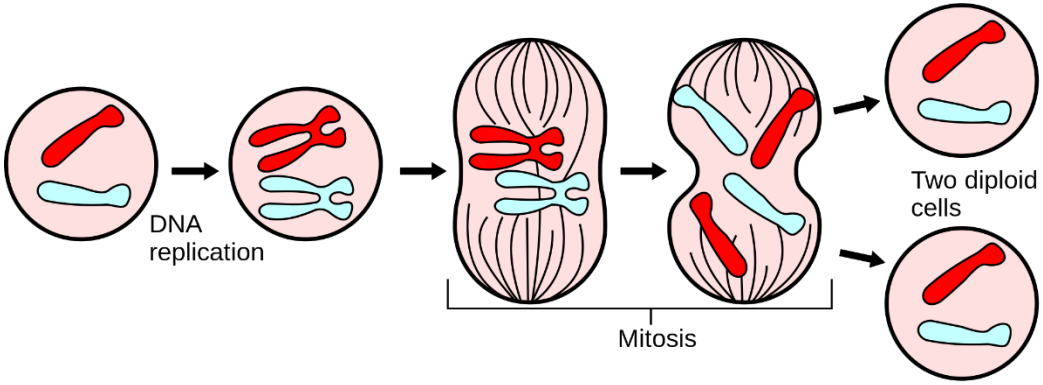


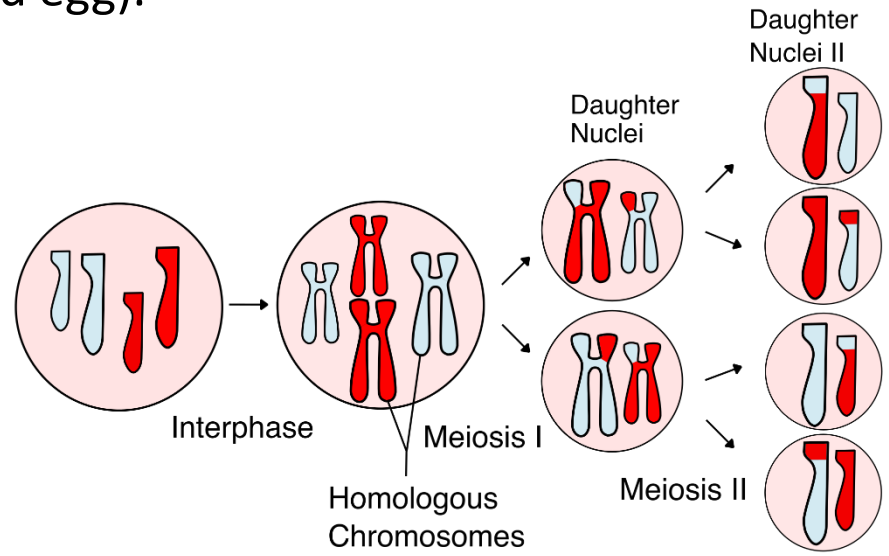
Image: Mysid

The primary result of mitosis is the division of the parent cell into two daughter cells which are genetically identical to each other.

The cell

Cell division: Meiosis

Meiosis is a specialized type of cell division that ***reduces the chromosome number of the daughter cells by half***. This process occurs in all sexually reproducing eukaryotes to produce **gametes** (e.g.: sperm and egg).



Because the number of chromosomes is halved during meiosis, gametes can fuse (fertilization) to form an eukaryotic cell (zygote) that contains two copies of each chromosome, one from each parent.

Organisms

A **life form** (***organism***) is an assembly of organized and complex matter that presents the following properties:

- ✓ It is composed of one or more basic units called ***cells***.
- ✓ It maintains and regulates the balance of its bodily functions (***homeostasis***).
- ✓ It responds to external stimuli.
- ✓ It grows and develops (***metabolism***).
- ✓ It does the basic functions of ***nutrition***, ***relationship*** and ***reproduction***.
- ✓ It is able to evolve and adapt to the environment.

Organisms

Chemical composition: bioelements

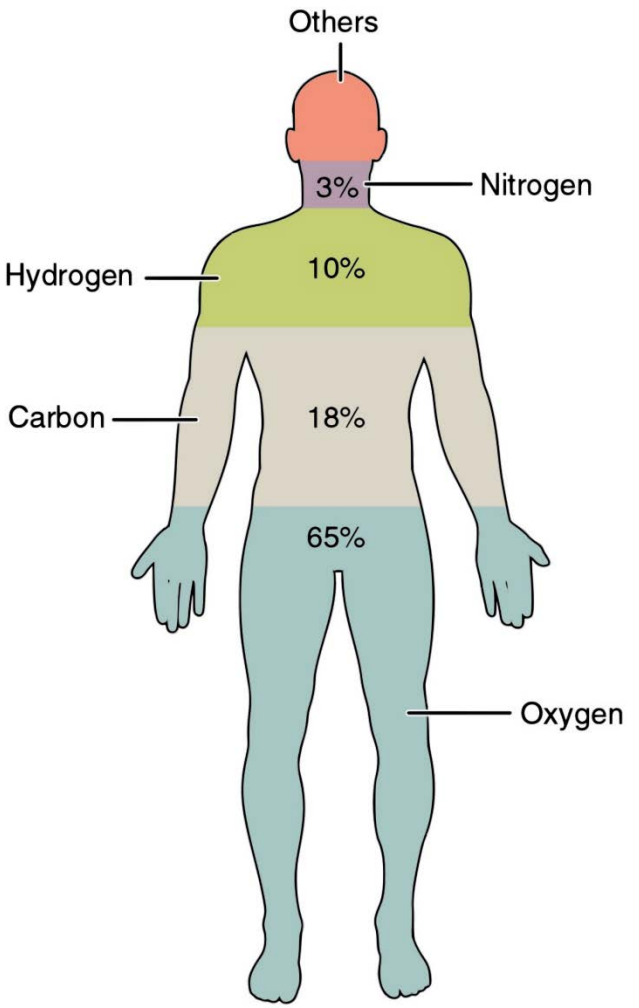
The most abundant chemical elements found in organisms are called **bioelements**.

Bioelement	% in living matter	atoms
Primary	96	**Carbon** (C), **Hydrogen** (H), **Oxygen** (O), **Nitrogen** (N), **Phosphorus** (P), **Sulfur** (S)
Secondary	3.9	Calcium (Ca), Sodium (Na), Potassium (K), Chlorine (Cl), Iodine (I), Magnesium (Mg), Iron (Fe)
Trace elements	0.1	Copper (Cu), Zinc (Zn), Manganese (Mn), Cobalt (Co), Molybdenum (Mo), Nickel (Ni), Silicon (Si) ...

- ***Carbon is the common element of all known life*** given its abundance in the universe and its ability to form large and complex molecules with many different atoms.

Organisms

Chemical composition: bioelements

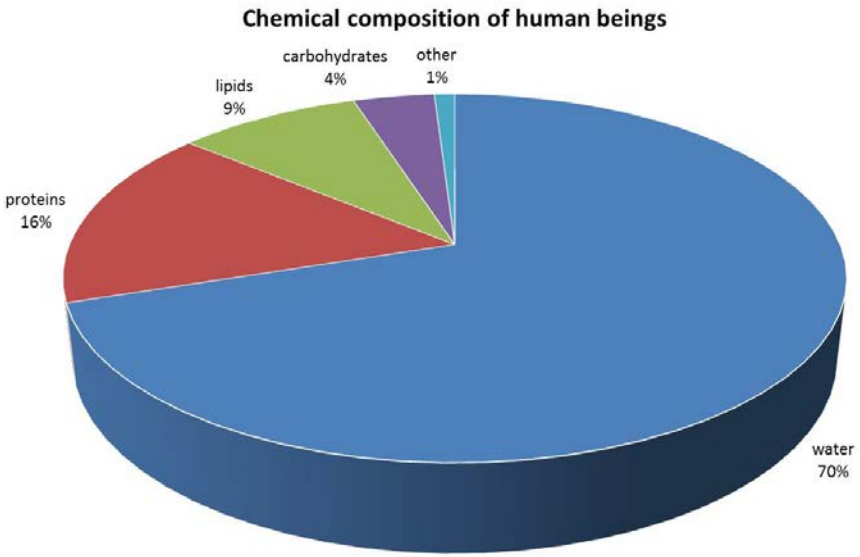


Organisms

Chemical composition: biomolecules

Bioelements are combined to create the molecules of which organisms are made of (**biomolecules**).

- **Inorganic:** water and mineral salts.
- **Organic:** carbohydrates, lipids, proteins, and nucleic acids.



Organisms

Chemical composition: inorganic biomolecules

- **Water *is vital for all known organisms***. It transports substances, regulates body temperature and is the medium in which the organism's internal activity occurs.

- **Mineral salts** (*silicates, $CaCO_3$, Na^+, K^+, etc.*) have a ***structural function*** in organisms (*e.g., giving rigidity to bones, mollusk shells, egg shells, etc.*) and a ***regulation*** one (*e.g., contraction of muscles, transmission of nerve impulses, regulate pH changes, control the movement of water through cells by osmosis, etc.*).

Organisms

Chemical composition: organic biomolecules

Carbohydrates consist of ***carbon***, ***hydrogen***, and ***oxygen***. They are also called ***sugars*** or ***saccharides***.

Image: Elisa Azzali
CC BY 2.0

The function of carbohydrates is mainly to ***store energy***, being used as energy source either immediately (*glucose*) or as a reserve (*starch*, *glycogen*). Some also have a ***structural function***, being a component pf the cell wall of plants (*cellulose*) or the exoskeleton of arthropods (*chitin*).

Organisms

Chemical composition: organic biomolecules

Lipids consist mainly of ***carbon*** and ***hydrogen***, with some **oxygen**. They can also contain ***phosphorus***, ***sulfur*** and ***nitrogen***. Lipids are ***hydrophobic***, i.e., they do not (or do not easily) dissolve in water.

The main functions of lipids include **storing energy** (*triglycerides*), structural function (*lipid bilayers* of cell membranes), and **regulation** (*steroid hormones* that regulate metabolism and reproduction).

Organisms

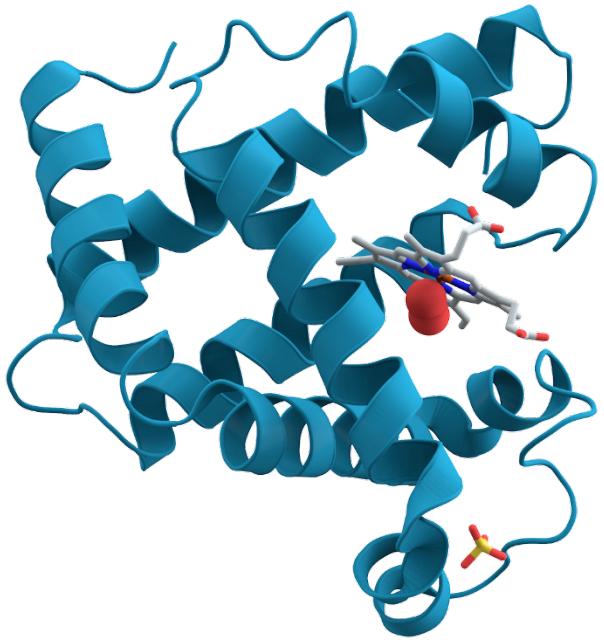
Chemical composition: organic biomolecules

Proteins are large biomolecules made from ***amino acids***, which are organic compounds composed of ***carbon***, ***hydrogen***, ***oxygen***, and ***nitrogen***.

Proteins differ from one another in their sequence of amino acids, which is encoded in the genetic material of each organism.

The main functions of proteins are:

- **structural function**, such as *collagen*, which is found in the tendons, ligaments and skin, or *keratin*, which is found in the hair and nails.
- **cellular function**, participating in many vital biochemical reactions and processes as *enzymes*, *hemoglobin*, *antibodies*, etc.



Organisms

Chemical composition: organic biomolecules

Nucleic acids are complex biomolecules which store the ***genetic information*** in every living organism.

Their function is to transmit and express the genetic information inside and outside the cell nucleus (next generation of organisms).

The two most common nucleic acids are:

- **Deoxyribonucleic acid (DNA)**, which contains the genetic instructions used in the development and functioning of all known living organisms.
- **Ribonucleic acid (RNA)**, which converts the genetic information stored in the DNA into the amino acid sequences of proteins.

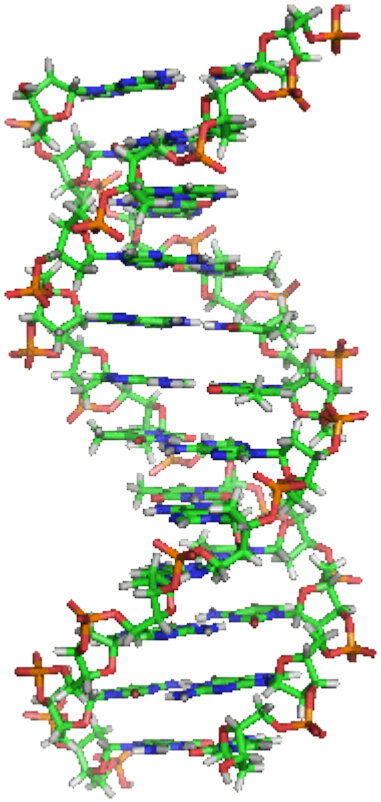


Image: Zephyris at the English language Wikipedia

Organisms

Organization

Organisms are all composed of basic units called **cells**.

Unicellular organisms consist of only one cell. Examples: *bacteria, protozoa, paramecia*.

Multicellular organisms consist of more than one cell. Examples: *animals, plants*.

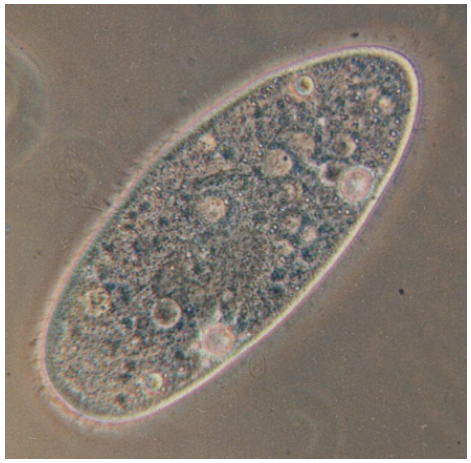


Image: Barfooz at the English Wikipedia

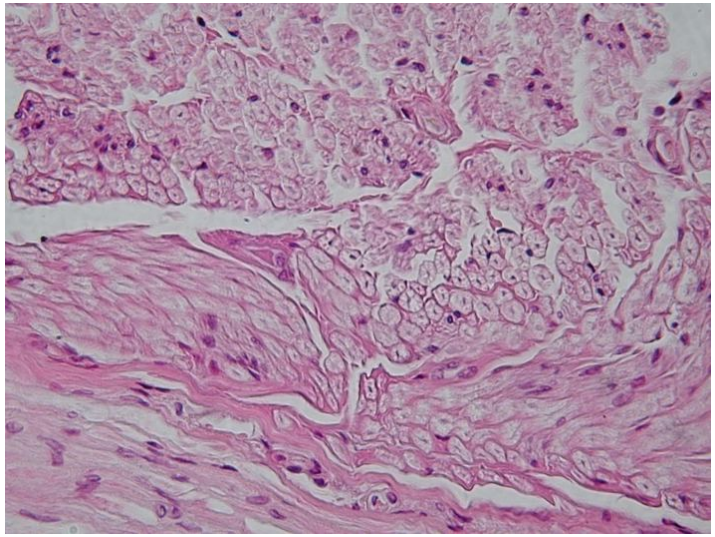
Image: Mikel Ortega / Richard Bartz

Organisms

Organization

Multicellular organisms are able to specialize their ***cells*** to carry out together a ***specific function***. A **tissue** is an ensemble of these cells.

Examples: *epithelium (epidermis), connective tissue (tendon), muscle tissue (biceps), nervous tissue (nerve)*.



Organisms

Organization

Several ***tissues*** can form a ***functional ensemble*** (**organ**) to work together to perform a specific activity.

Organs are grouped into ***organ systems***.

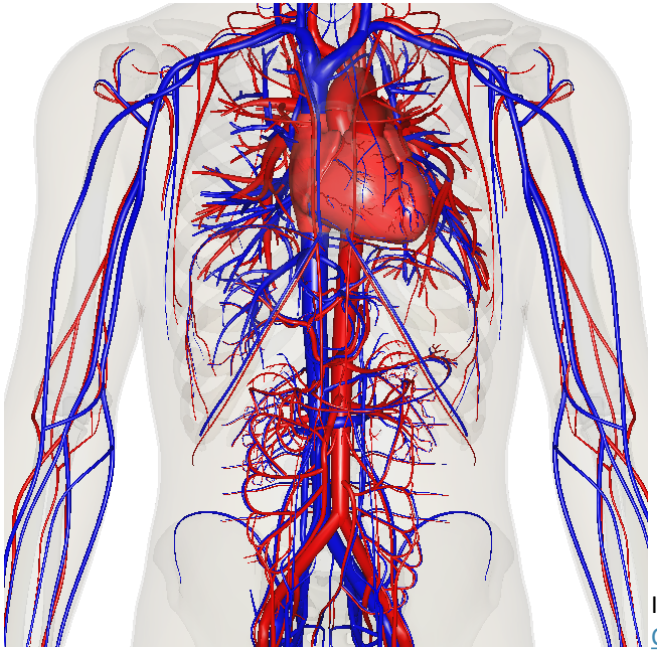


Image: BodyParts3D/Anatomography
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Example: *The heart is an organ of the circulatory system.*

Organisms

Organization

All organisms present different levels of organization with increasing complexity.

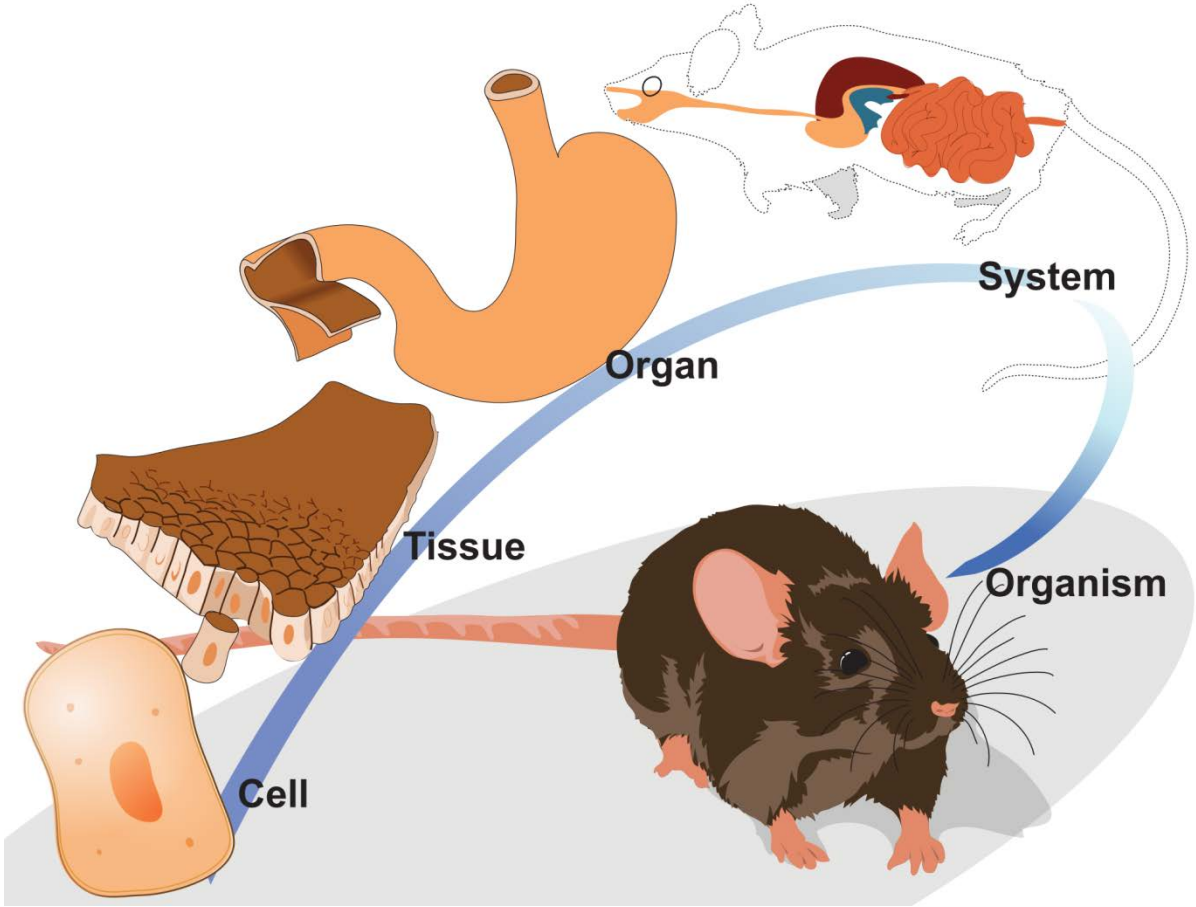

Image: LadyofHats
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Organisms

Classification

More than two million of different species are known to exist on Earth, and probably that is only a small fraction of the total number of organisms that inhabit the planet.

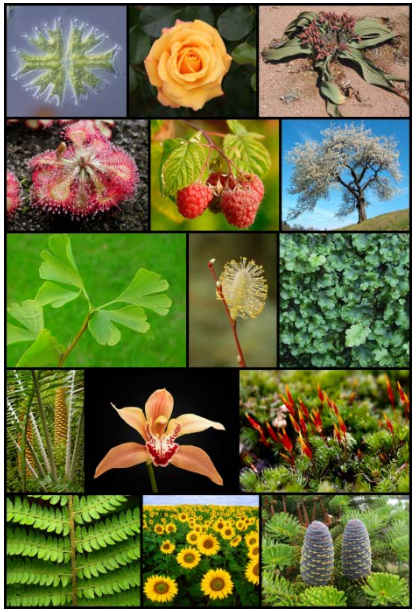

Image: Rkitko
GFDL

Image: Medeis

In order to study this great variety of organisms, we need to group them, i.e., classify them. **Taxonomy** is the science of ***classification of organisms***.

Organisms

Classification

Aristotle (384–322 BC) classified about 500 animals and distinguished between ***animals without blood*** and ***animals with blood***.

Theophrastus (371–287 BC) classified some 500 plants into ***herbs***, ***shrubs***, and ***trees***.

St. Augustine (354–430) classified animals into three categories: ***useful***, ***dangerous*** and ***superfluous***.

Organisms

Classification

Carl von Linnaeus (1707–1778) was the first to list and systematically classify all the known organisms of his time (~ 10 000).

He developed the **binomial nomenclature**, which is the formal system of naming species of organisms.

It consists in giving each species a name composed of two words in Latin. The first word (***generic name***) identifies the genus to which the species belongs, and the second word (***specific name***) identifies the species within the genus.

Example: *Canis familiaris (dog) and Canis lupus (wolf)*.

Image: Djmirko/Habj
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Image: Katerina Hlavata
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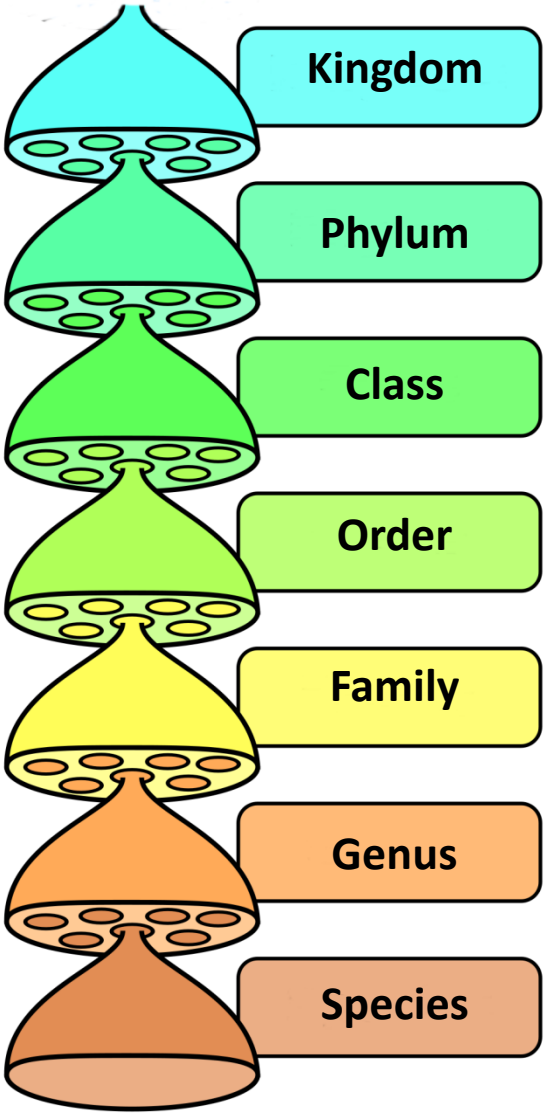
Organisms

Classification

There are the following taxonomic ranks:

- a **species** is the basic unit of classification. It is a large group of organisms with similar characteristics and in which two individuals can reproduce producing fertile offspring.
- Similar species are grouped into a **genus**.
- Similar genera are grouped into a **family**.
- Similar families are grouped into an **order**, similar orders into a **class**, and similar classes into a **phylum**.
- The highest taxonomic rank is the **kingdom**.



Organisms

Classification

Example: wolf

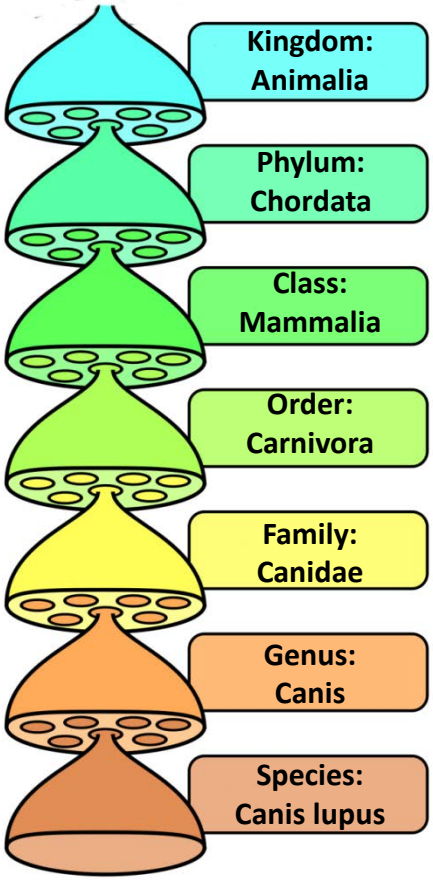


Image: Gustavo Girardelli / A.R. Esteve
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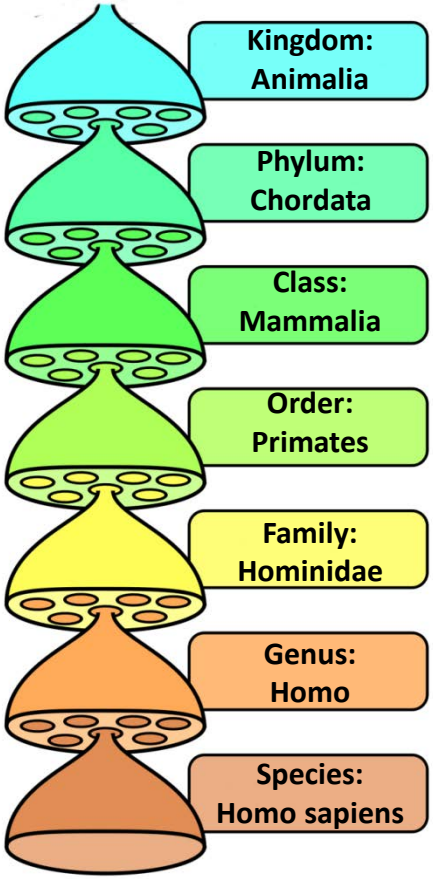
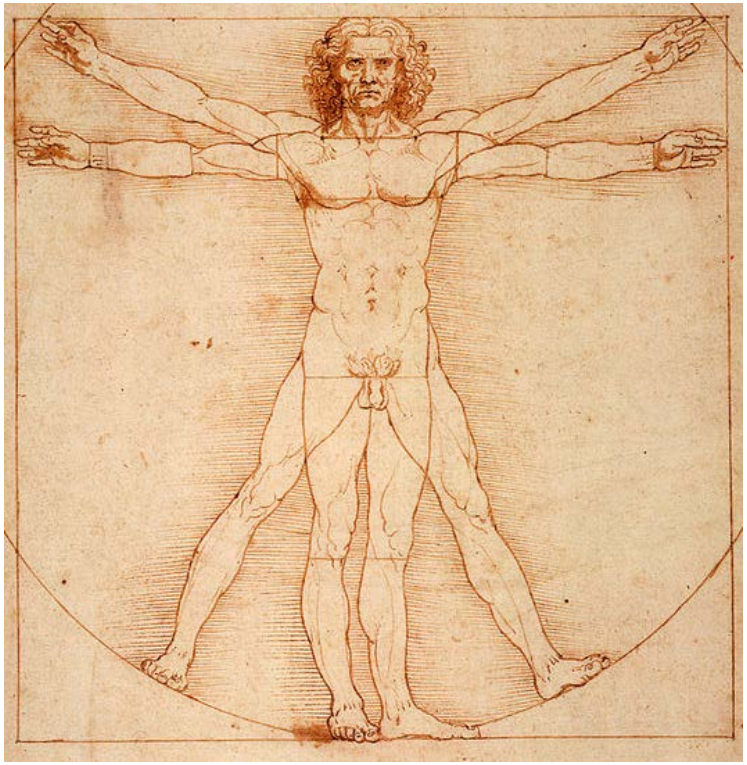
Organisms

Classification

Example: human





Uomo Vitruviano (Leonardo da Vinci)
Gallerie dell'Accademia (Venecia)

Organisms

Classification

Linnaeus considered that species were fixed and invariable, i.e., they had been created at the beginning of time and have been the same since.

His classification was based on the ***structural similarities of the different organisms***, but it didn't consider the possible relationships between organisms.

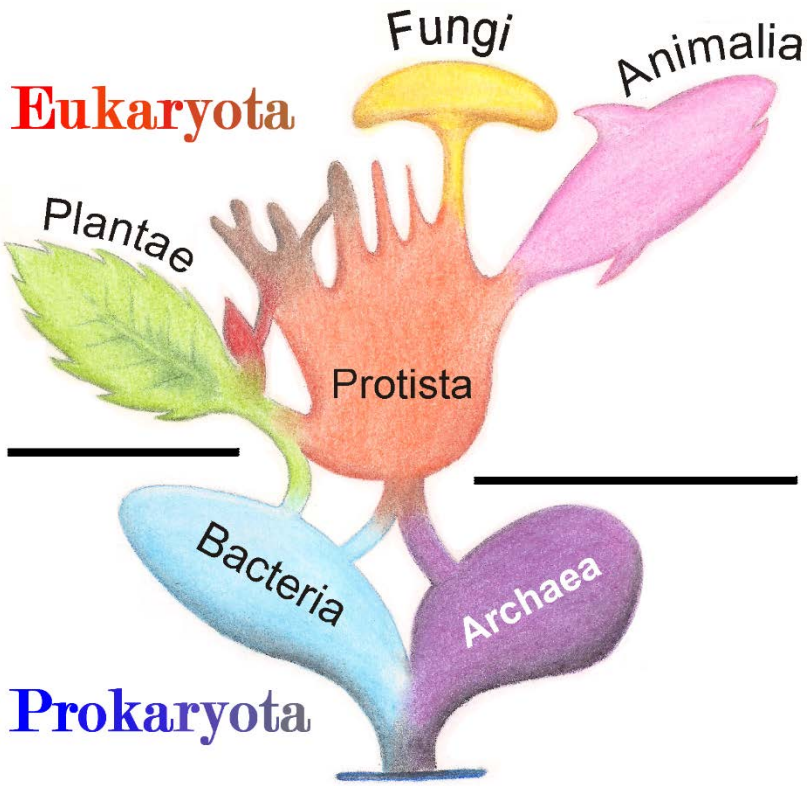
With the acceptance of ***evolution*** as the mechanism of biological diversity and species formation, scientists started to think that the structural similarities between different organisms could be due to the ***existence of a common ancestor***.

Nowadays, different criteria (DNA sequences, analysis of morphological characters, molecular characters, etc.) are used to classify organisms reflecting the presumptive evolutionary relationships between them. Therefore, classifications reflect the ***phylogeny*** (or *"family tree"*) of organisms showing their descent by evolution.

Organisms

Classification

All organisms can be classified into **six kingdoms** (Carl Woese, 1977), based on their similar characteristics.



Organisms

Classification: Archaea

This kingdom consists of **microorganisms** which are characterized by:

- being **prokaryotes**, i.e., they lack a nucleus or any other membrane-bound organelle.
- consisting of only one cell (**unicellular**).
- living in a ***broad range of habitats***, although many live in harsh environments.

Grand Prismatic Spring.
Yellowstone National Park, USA
Image: Jim Peaco, National Park Service

Organisms

Classification: Bacteria

This kingdom consists of **microorganisms** which are characterized by:

- being **prokaryotes**.
- being **unicellular**.
- being **small** (0.5 – 5 µm).
- living in a **broad range of habitats**.

Archaea and bacteria have important biochemical and genetic differences.

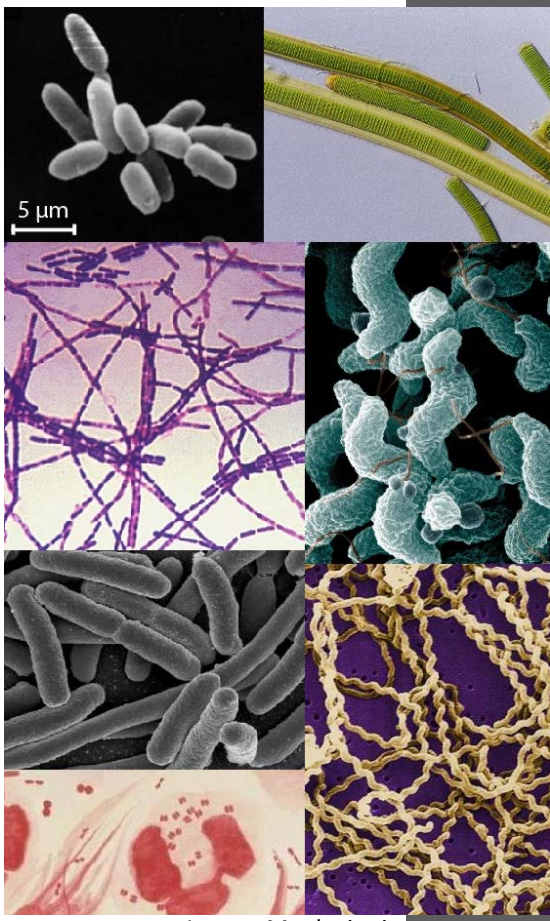


Image: Maulucioni

Organisms

Classification: Bacteria

Bacteria are the most abundant organisms on Earth.

- ✓ There are beneficial bacteria, such as those use in the preparation of ***fermented foods*** (*e.g., Lactobacillus*) or ***cyanobacteria***, which produce large amounts of oxygen.
- ✓ Many bacteria live in ***symbiotic association*** with humans, and are essential for our survival. Most of them live in the digestive tracts, but also a large number live in the skin.
- ✓ However, bacteria can also cause ***diseases*** (*e.g., Salmonella*, *Vibrio cholerae*, *Mycobacterium tuberculosis*, *Yersinia pestis*, etc.). Bacterial infections may be treated with ***antibiotics***, which kill bacteria or prevent bacterial growth.
- ✓ Some bacteria, which are called ***saprophytes***, decompose organic matter into inorganic matter.

Organisms

Classification: Protista

This kingdom consists of **unicellular** or **multicellular organisms** which have cells with nuclei (**eukaryotic**).

It consists of all those eukaryotic organisms that are not animals (*Animalia*), plants (*Plantae*) or fungi (*Fungi*).

Organisms

Image: Barfooz
CC BY-SA 3.0

Classification: Protista

They do not necessarily have much in common, but they can usually be subdivided into:

- **protozoa**, which are ***unicellular eukaryotes*** that feed on organic matter from other organisms (***heterotrophs***).

  Examples: Paramecium Aurelia, Amoeba proteus, Plasmodium falciparum (malaria), Trypanosoma brucei gambiense (sleeping sickness).

- **algae**, which are ***unicellular*** or ***multicellular eukaryotes*** that produce organic matter from inorganic substances (***photosynthetic autotrophs***).

  Example: Laurencia, Laminariales.

Image: Stef Maruch
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Organisms

Classification: Fungi

This kingdom consists of **unicellular** or **multicellular eukaryotes** which feed on organic matter from other organisms (**heterotrophs**).

Image: BorgQueen
CC BY-SA 2.5

Fungi can be subdivided into: **yeasts**, **moulds**, and **mushrooms**.

Organisms

Classification: Fungi

There are edible fungi (*e.g., Agaricus bisporus*, *Lactarius sanguifluus*), but many species are poisonous to humans (*e.g., Amanita phalloides*). Nevertheless, some fungi are used to produce foods and alcoholic beverages (*e.g., Saccharomyces cerevisiae*) or medicines (*e.g., penicillin*).

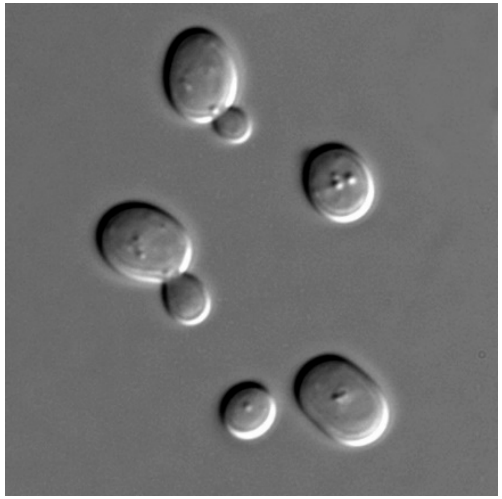

Image: Masur

Image: Roger McLassus 1951
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Organisms

Classification: Plantae

This kingdom consists of **multicellular eukaryotes** which are **autotrophs**. The main characteristic of plants is that they are able to carry out ***photosynthesis***.

Images: Rkitko
GFDL

Organisms

Classification: Plantae

Photosynthesis is a process in which plants absorb ***solar energy*** using the ***chlorophyll*** stored in the ***chloroplasts*** to synthesize organic matter (carbohydrates) from inorganic substances (water and CO_2). ***Oxygen*** is also released as a waste product.

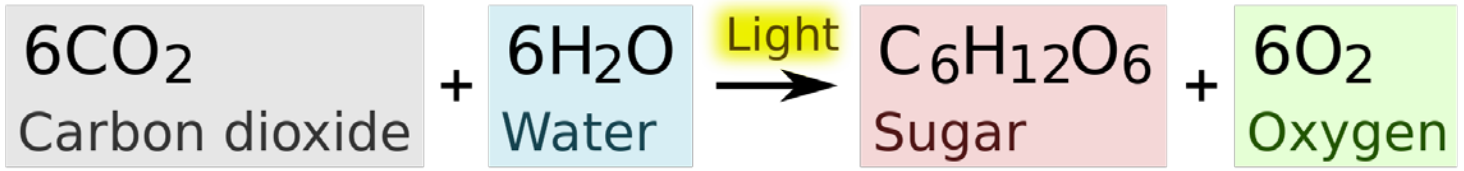


Image: ZooFari

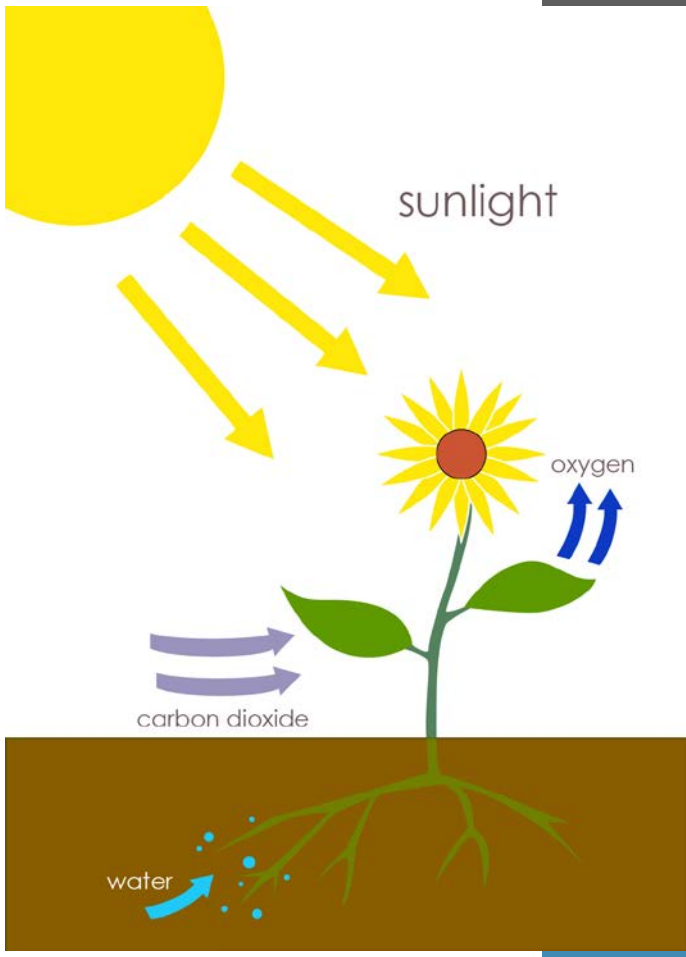
Photosynthesis occurs in two stages:

- **light-dependent reactions**: plants absorb light energy and convert it into chemical energy. These only occur during the day.
- **light-independent reactions:** plants synthesize carbohydrates from CO_2 and water using the chemical energy obtained during the light-dependent reactions. These occur during both day and night.

Organisms

Classification: Plantae

- ✓ Plants absorb water and salts from the soil through their roots and transport them to their leaves.
- ✓ Plants absorb CO_2 from the air through their leaves.
- ✓ During ***photosynthesis***, plants synthesize ***organic matter*** from water, salts, and CO_2 using solar energy. ***Oxygen*** is released during this process.
- ✓ The synthesized nutrients are distributed throughout the plant.
- ✓ During ***respiration***, plants absorb oxygen and convert the nutrients obtained during the photosynthesis into ***energy***. ***CO_2*** is released during this process.



Organisms

Classification: Plantae

Land plants are classified into:

<table>
<tr><td>bryophytes</td><td colspan="3">liverworts
mosses
hornworts</td></tr>
<tr><td rowspan="3">vascular plants</td><td>pteridophytes</td><td colspan="2">lycophytes
horsetails
ferns</td></tr>
<tr><td rowspan="2">spermatophytes</td><td>gymnosperms</td><td>cycads
Ginkgo
conifers
gnetophytes</td></tr>
<tr><td>angiosperms</td><td>monocotyledon
dicotyledon</td></tr>
</table>

Organisms

Classification: Plantae

Bryophytes are very simple plants, ***without roots, stems or leaves***. They ***do not produce flowers or seeds***. They reproduce via ***spores***. They are limited in size and prefer moist habitats.

They are classified into: ***liverworts***, ***mosses***, and ***hornworts***.

Organisms

Classification: Plantae

Vascular plants have a more complex organization, with ***roots***, ***stems***, and ***leaves***.

They are classified into: ***pteridophytes*** and ***spermatophytes***.

Organisms

Classification: Plantae

The structure of vascular plants generally include two major organ systems:

- a **root system**, which has the functions of absorbing water and inorganic nutrients and anchoring the plant to the ground. It typically lies below the surface of the soil. It ususally consists of a primary root and secondary roots.
- a **shoot system**, composed of ***stems*** and ***leaves***. The stem keeps the leaves in the light and provides a place for the plant to keep its flowers and fruits. Leaves are specialized for photosynthesis.

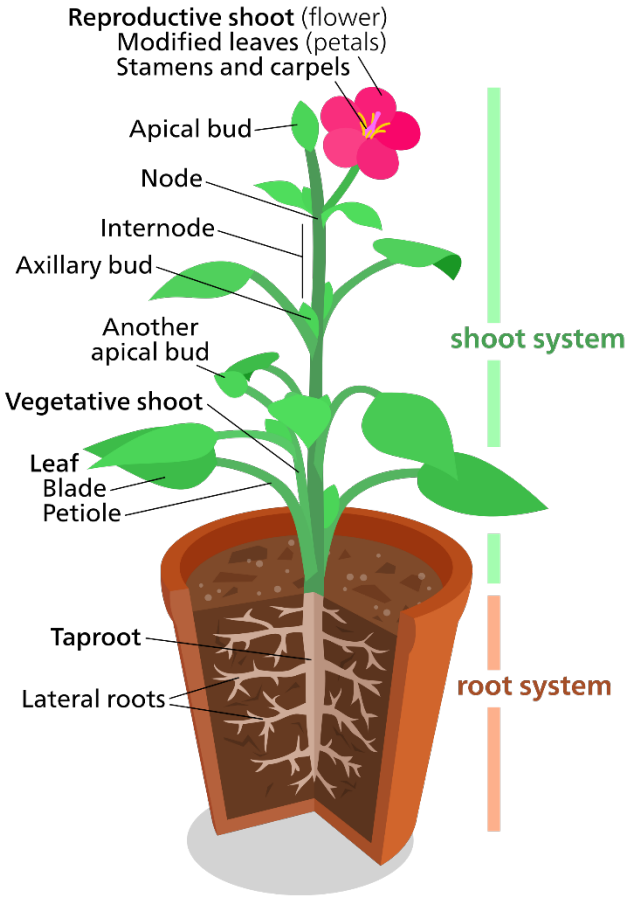


Image: Kelvinsong
CC BY 3.0

Organisms

Classification: Plantae

Pteridophytes are ***vascular plants*** that ***reproduce via spores*** and ***have neither seeds nor flowers***.

They are classified into: ***lycophytes***, ***horsetails*** and ***ferns***.

Organisms

Classification: Plantae

Spermatophytes are ***vascular plants*** that ***produce seeds***.

They are classified into:

- **Gymnosperms**: plants that produce ***seeds without an enclosure*** (i.e., without fruit). Their ***seeds develop inside cones***. They ***do not produce flowers***. They are classified into: ***cycads***, ***Ginkgo***, ***conifers***, and ***gnetophytes***.
- **Angiosperms**: plants that ***produce flowers and seeds***. They ***produce fruits*** that contain the seeds. The flower is their reproductive organ. They are classified into: ***monocotyledon*** (seeds contain only one embryonic leaf) and ***dicotyledon*** (seeds contain two embryonic leaves).

Image: JJ Harrison
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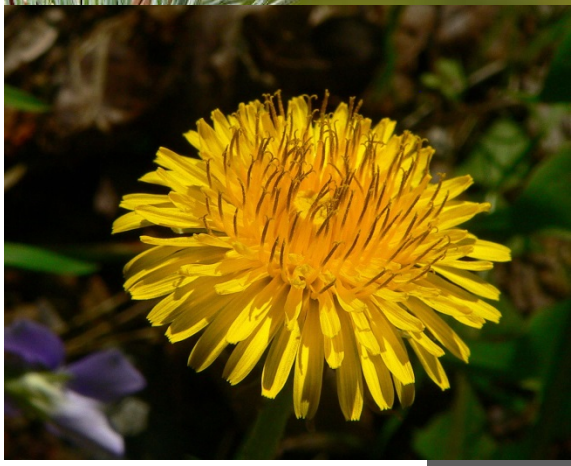

Image: Greg Hume
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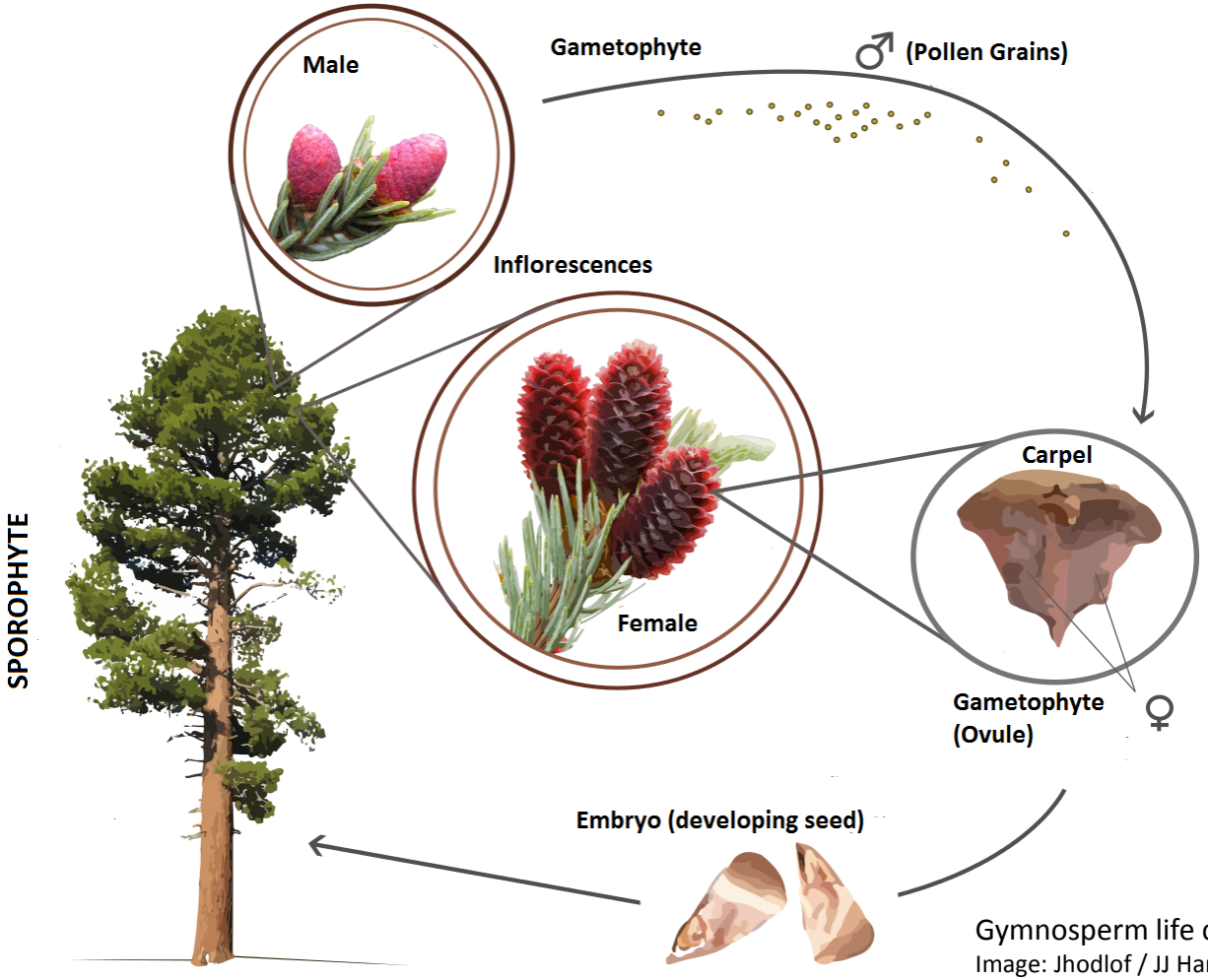
Organisms

Classification: Plantae



Gymnosperm life cycle

Organisms

Classification: Plantae

The **flower** is the reproductive organ of angiosperms.

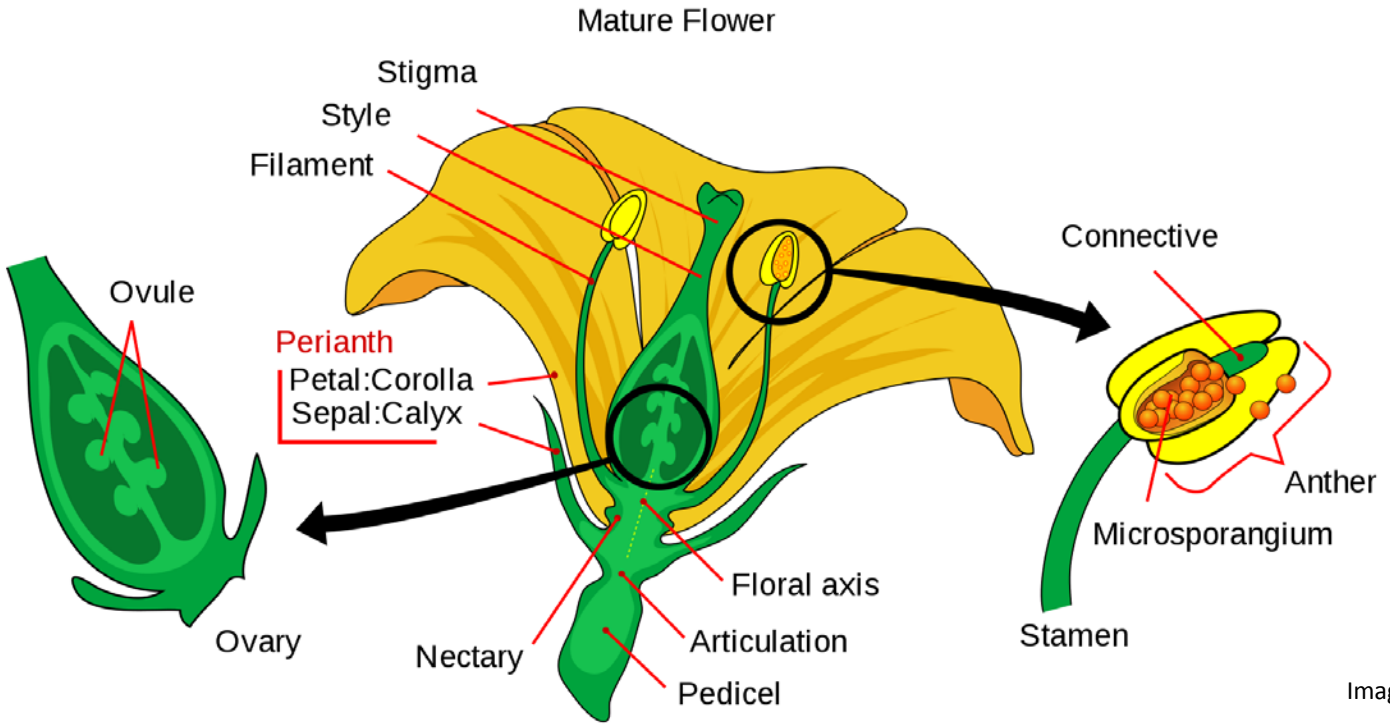


Image: LadyofHats

Flowers may allow outcrossing (fusion of pollen and ovules from different individuals) or selfing (fusion of pollen and ovules from the same flower).

Organisms

Classification: Plantae

The **flower** is the reproductive organ of angiosperms.

- **Calyx**: consists of units called ***sepals***, which are typically green and function as protection for the flower in the bud stage and as support for the petals when in bloom.
- **Corolla**: consists of units called ***petals***, which are typically thin, soft and brightly colored to attract animals that help the process of pollination.
- **Androecium**: consists of units called **stamens**, which are composed by a stalk called a ***filament***, topped by an ***anther*** where ***pollen*** is produced. It is the male part of the flower.
- **Gynoecium** (a.k.a. **pistil**): consists of one or more units called ***carpels***, which form a hollow structure called ***ovary***, which produces ***ovules*** internally. It typically consists of the ovary, the style, and the stigma. It is the female part of the flower.

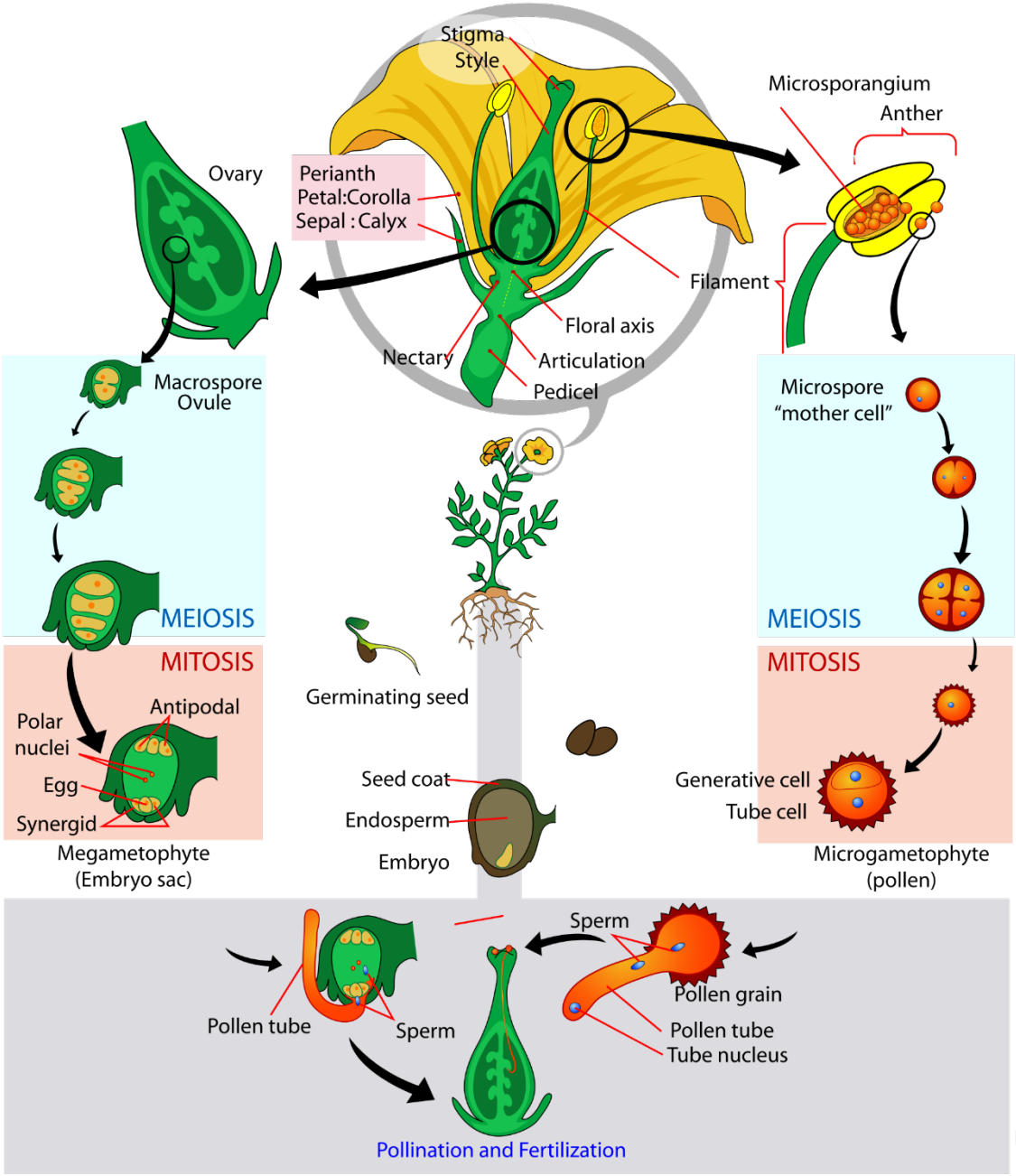


Image: LadyofHats

Organisms

Classification: Plantae

The **sexual reproduction** of plants consists of the following phases:

1) **Pollination** is the transfer of ***pollen*** from the ***anthers*** of a plant to the ***stigma*** of a plant, most often by an animal or by wind.
2) **Fertilization** is the fusion of gametes forming a ***zygote*** to initiate the development of the ***embryo***.
3) **Seed development** is the formation of the seed from the fertilized ovules, which undergo marked changes to develop a seed coat around the embryo and its nutritive tissue.
4) **Fruit development** is the formation of the structure containing the seed as a result of the ripening of the ovary. Fruits are the means by which angiosperms ***disseminate seeds***.
5) **Germination** is the sprouting of a seed and growth of the ***plant*** contained within it. Under proper conditions, the seed begins to germinate and the embryonic tissues resume growth.

Organisms

Classification: Animalia

This kingdom consists of **multicellular eukaryotes** which are **heterotrophs**. Most animal bodies are differentiated into ***tissues***. Animals are ***able to move*** during all or part of their life cycle.

Images: Medeis

Organisms

Classification: Animalia

Animals are classified into 2 large groups:

- **Invertebrates:** animals without a backbone or bony skeleton. Some have a hard outer casing called exoskeleton that protects their body. They are very diverse. The majority of animal species are invertebrates. They are classified into: ***porifera***, ***platyhelminths***, ***nematodes***, ***cnidarian***, ***annelids***, ***molluscs***, ***arthropods***, and ***echinoderms***.
- **Vertebrates:** animals with a backbone and a skeleton (endoskeleton) made up of bone and cartilage. Most have a bilaterally symmetric body plan, divided into three different regions: head, torso, and limbs. They are classified into: ***fish***, ***amphibians***, ***reptiles***, ***birds***, and ***mammals***.

Organisms

Classification: Animalia - invertebrates

Porifera are ***aquatic*** animals that are usually immobile and permanently attached to something (***sessile***). They do not have tissues and organs, but they ***have unspecialized cells that can transform into other types***. They have ***no body symmetry***, and their bodies are ***full of pores*** and channels allowing water to flow through them. Their reproduction is both ***sexual*** (external fertilization) and ***asexual*** (fragmentation or budding).

Example: sponges.

Organisms

Classification: Animalia - invertebrates

Platyhelminths (a.k.a. ***flatworms***) are relatively simple animals, with no internal body cavity and a flattened shape. They have ***bilateral symmetry***. There are ***free-living species*** (in marine, fluvial, humid terrestrial, and aerial habitats) and ***parasitic species*** (living on or in several hosts). The vast majority are ***hermaphrodites***. They always reproduce ***sexually*** (internal fertilization).

Example: Taenia solium (pork tapeworm).

Organisms

Classification: Animalia - invertebrates

Nematodes (a.k.a. ***roundworms***) are small animals with a long cylindrical tube-like ***non-segmented body*** and ***no limbs***. They have ***bilateral symmetry***. They have a tubular ***digestive system*** with openings at both ends and ***sexual organs***. There are ***free-living species*** in a broad range of environments, but also ***parasitic species***.

Example: Anisakis.

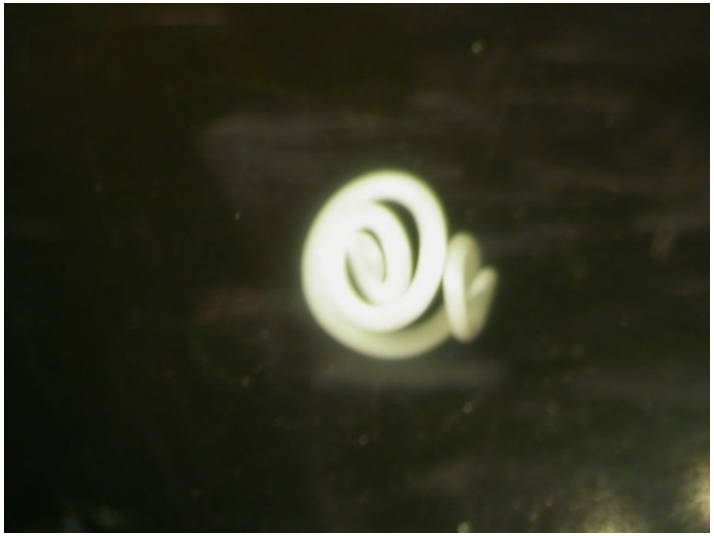


Image: Anilocra at English Wikipedia

Organisms

Classification: Animalia - invertebrates

Cnidarians are ***aquatic*** animals, mostly found in ***marine environments***, which have special cells in their ***tentacles*** that release a ***stinging toxin*** which is used for prey capture and defense from predators. They have a ***simple nervous system*** and ***sensory organs***. They have ***radial symmetry***. They have two basic body forms: ***swimming medusae*** and ***sessile polyps***. There are ***free-living species***, but also species that produce ***colonies***. Their reproduction is both ***sexual*** and ***asexual***.

Examples: jellyfish, corals, sea anemones.

Image: Sanjay Acharya
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Image: Toby Hudson
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Organisms

Classification: Animalia - invertebrates

Annelids (a.k.a. ***ringed worms***) are animals with a long cylindrical tube-like ***segmented body*** and ***parapodia*** that function as limbs. They have ***bilateral symmetry***. They have ***tissues*** and ***organs***. They are mostly found in ***moist environments***. Although they usually reproduce ***sexually***, some species can reproduce ***asexually*** (by fragmentation or by budding).

Examples: earthworms, leeches.

Image: Pieria

Organisms

Classification: Animalia - invertebrates

Molluscs are animals with a ***non-segmented soft body*** (divided into a head, a muscular foot, and a visceral mass). Their body is usually covered by a ***hard exoskeleton*** which encloses and protects their soft parts. They have ***bilateral symmetry***. They have ***tissues*** and ***organs***. They are very diverse, living in a ***broad range of habitats***. They usually reproduce ***sexually***.

Examples: ***gastropods*** *(snails, slugs),* ***bivalves*** *(mussels, clams, oysters),* ***cephalopods*** *(squid, cuttlefish, octopus).*

Image: Jürgen Schoner
CC BY-SA 3.0

Image: Mark A. Wilson
Department of Geology, The College of Wooster

Image: Yoruno
CC BY-SA 3.0

Organisms

Classification: Animalia - invertebrates

Arthropods are animals which have an ***external skeleton*** (exoskeleton), a ***segmented body*** (head, thorax, and abdomen), and ***paired jointed appendages*** (legs, antennae). They replace their exoskeletons by ***moulting***, i.e., shedding the old exoskeleton after growing a new one that is not yet hardened. They have ***bilateral symmetry***. They are the most diverse group of animals, living in a ***broad range of habitats***. They usually reproduce ***sexually***.

Examples: ***insects*** *(grasshoppers, bees),* ***arachnids*** *(scorpions, spiders),* ***crustaceans*** *(prawns, crabs),* ***myriapods*** *(centipedes).*

Image: Ivar Leidus
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Image: André Karwath
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Image: SEFSC Pascagoula Laboratory
Collection of Brandi Noble, NOAA/NMFS/SEFSC

Organisms

Classification: Animalia - invertebrates

Echinoderms are ***marine*** animals with an ***internal skeleton*** composed of ***calcareous plates***. Some species have spines. Adults have ***radial symmetry***, although their larvae have bilateral symmetry. They have a unique water vascular system for locomotion, food and waste transportation, and respiration. They usually reproduce ***sexually***, although most are able to reproduce asexually and regenerate tissue, organs, and limbs.

Examples: starfish, sea urchins.

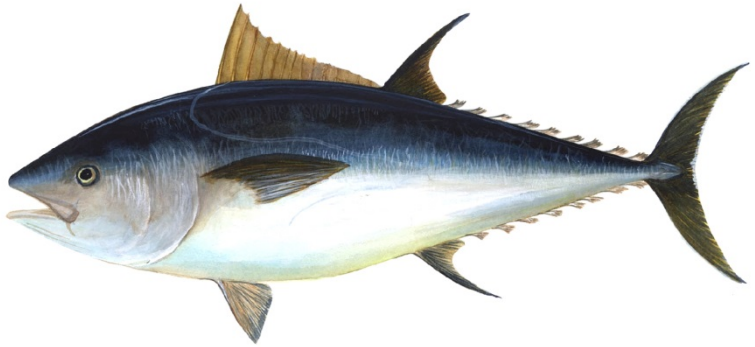
Organisms

Classification: Animalia - vertebrates

Fish are ***aquatic*** animals that have ***gills*** for breathing and whose limbs are in the shape of ***fins***. Their skin is usually covered with ***scales***. They rely on their environment to mantain their body temperature (***cold blooded organisms***). They reproduce ***sexually***, and most of them lay eggs which develop outside the mother's body.

Examples: sharks, rays, salmon, tuna.

Image: Terry Goss
CC BY 2.5



Organisms

Classification: Animalia - vertebrates

Amphibians are animals that generally start out as ***larvae with gills*** living in water, and undergo ***metamorphosis*** to an ***adult form with lungs***. They have ***four limbs***. Their thin and ***delicate skin*** is ***permeable to water***. They rely on their environment to mantain their body temperature (***cold blooded organisms***). They reproduce ***sexually***, most of them requiring fresh water to lay their eggs.

Examples: frogs, toads, newts, salamanders.

Organisms

Classification: Animalia - vertebrates

Reptiles are animals that have their body covered in ***scales***. They have ***four limbs*** (except snakes). They all breathe using ***lungs***. They rely on their environment to mantain their body temperature (***cold blooded organisms***). They reproduce ***sexually***, and most of them lay eggs which develop outside the mother's body.

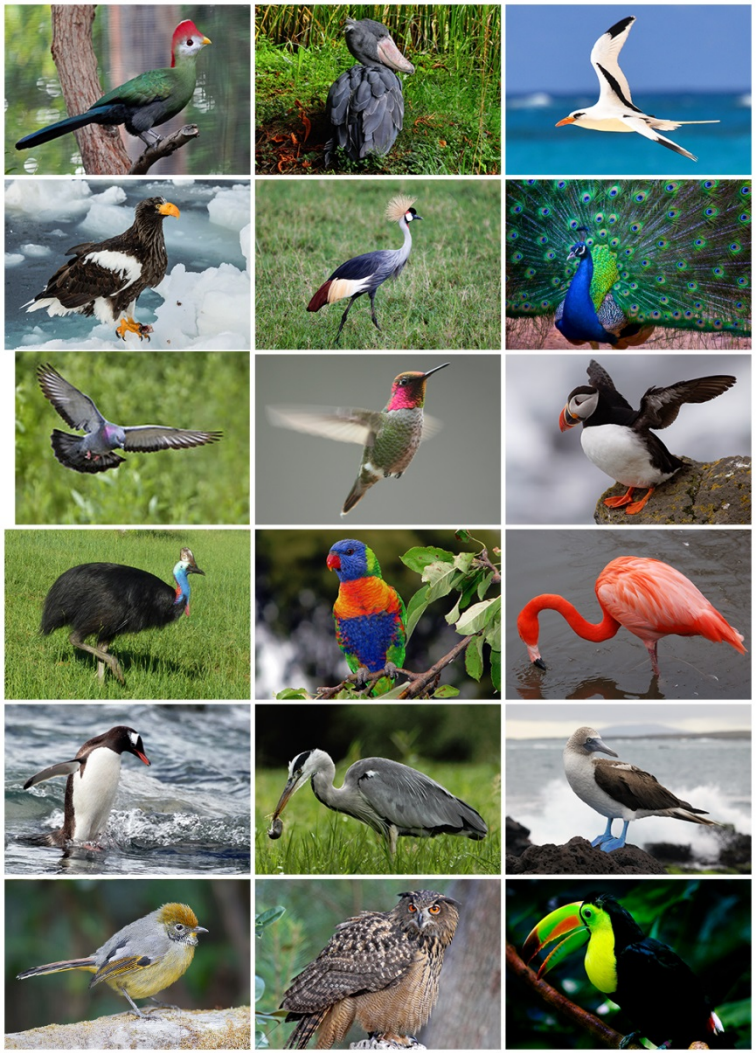
Examples: lizards, snakes, crocodiles, turtles.

Organisms

Classification: Animalia - vertebrates

Birds are animals that have ***wings*** which evolved from forelimbs. Many birds fly, but not all of them. They have a ***lightweight skeleton***. Their body is covered in ***feathers***. They have a ***toothless beak***. They all breathe using ***lungs***. They are able to mantain their own body temperature (***warm blooded organisms***). They reproduce ***sexually***, and most of them lay eggs which develop outside the mother's body.

Examples: ostriches, eagles, sparrows, owls, ducks.



Organisms

Classification: Animalia - vertebrates

Mammals are animals that have ***mammary glands*** (all females nurse their young with ***milk*** secreted from them). Their body is covered with ***hair***. They all have a special part in their brain involved in ***higher-order brain functions*** (sensory perception, cognition, language, etc.). They all breathe using ***lungs***. They are able to mantain their own body temperature (***warm blooded organisms***). They reproduce ***sexually***.

Examples: ***placentals*** *(gorillas, dogs, bats),* ***marsupials*** *(kangaroos, koalas),* ***monotremes*** *(platypuses, echidnas).*

Organisms

Classification

Kingdom	Archaea	Bacteria	Protista	Fungi	Plantae	Animalia
Cell number	unicellular	unicellular	unicellular multicellular	unicellular multicellular	multicellular	multicellular
Cell type	prokaryotes	prokaryotes	eukaryotes	eukaryotes	eukaryotes	eukaryotes
Feeding	autotrophs heterotrophs	autotrophs heterotrophs	autotrophs heterotrophs	heterotrophs	autotrophs	heterotrophs
Organisms	archaea	bacteria	protozoa algae	yeasts moulds mushrooms	bryophytes vascular plants (pteridophytes, spermatophytes)	vertebrate (fish, reptiles, mammals, etc.) invertebrates (sponges, mollusks, arthropods, etc.)

Ecosystems

An **ecosystem** is a community made up of living organisms (***biocoenosis*** or ***biological community***) and the natural environment in which they live (***biotope***). The living and non-living components of the ecosystem interact through nutrient cycles and energy flows.

Earth's ecosystems can be grouped into:

- **Terrestrial ecosystems**: forests, shrubland, meadows, deserts, steppes, savanna, tundra, etc.
- **Aquatic ecosystems**: marine (beaches, coral reefs, etc.) and freshwater (rivers, lakes, etc.).

Great barrier reef.
Image: (c) 2004 Richard Ling
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Ecosystems

Image: LA turrita

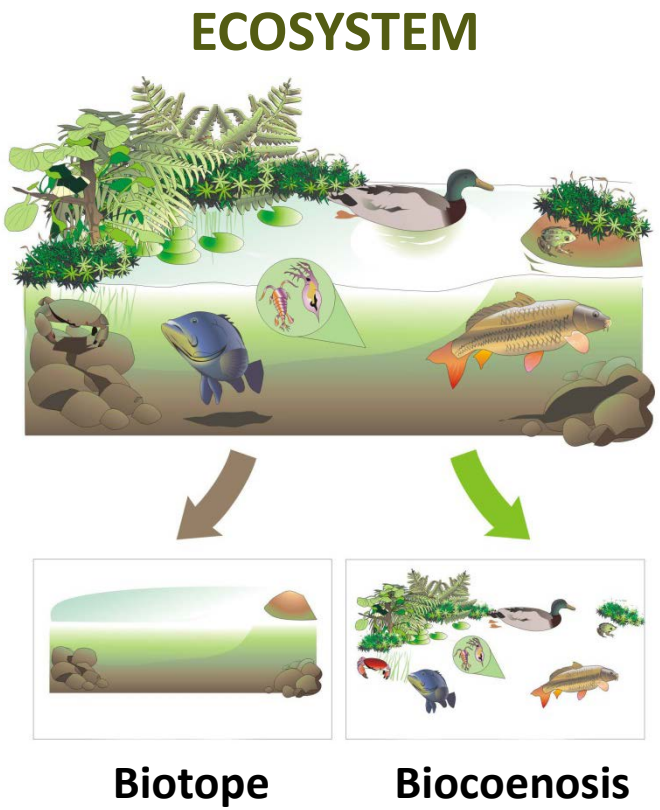
Ecosystems

Components of ecosystems

An ecosystem is made up of:

- the ***biotope***, which consists of the ***non-living chemical and physical parts of the natural environment*** that affect living organisms (water, light, temperature, humidity, atmosphere, and soil).

- the ***biocoenosis*** (or biological community), which consists of the ***living organisms*** that live in the ecosystem.



Ecosystems

Biological interactions

The organisms in an ecosystem interact with each other in order to obtain food, reproduce, protect from predators, etc.

The biological interactions can be classified into two groups:

- **Intraspecific relationships** involve ***individuals of the same species***.
- **Interspecific relationships** involve ***individuals of different species***.

Ecosystems

Biological interactions

Intraspecific relationships involve ***individuals of the same species***. These can be classified into:

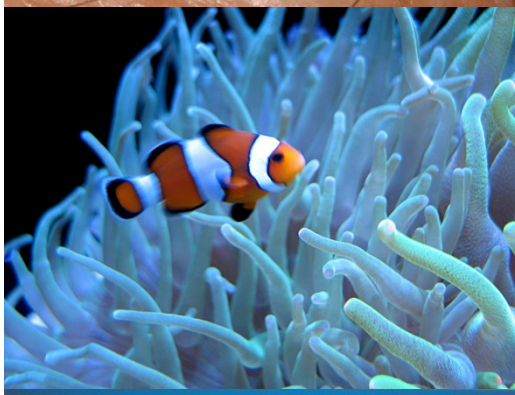
- **Competition:** individuals compete ***over resources*** (*e.g., food, water, territory, sexual partners*) if they become scarce. It is a negative interaction since individuals are harmed.
- **Cooperation:** individuals work together for ***common benefit*** (*e.g., to obtain food, to reproduce and protect the young*). It is a positive interaction since individuals are benefited. The main types of cooperation are: ***family*** (*e.g., lions, elephants*), ***gregarious association*** (*e.g., fish, penguins*), ***society*** (*e.g., bees, ants*), and ***colony*** (*e.g., coral*).

Ecosystems

Biological interactions

Interspecific relationships involve ***individuals of different species***. These can be classified into:

- **Predation:** one of the species (the ***predator***) hunts and kills other (the ***prey***). *Example: lion / antelope*.
- **Parasitism:** one of the species (the ***parasite***) lives on or in another organism (the ***host***), causing it some harm. *Example: tick / mammal*.
- **Mutualism:** two organisms of different species exist in a relationship in which ***each individual benefits from the activity of the other***. *Example: clownfish / anemone*.
- **Commensalism:** one organism (the ***commensal***) obtains food or other benefits from the other without affecting it. *Example: shark / remora*.



Ecosystems

Trophic interactions

Every organism in an ecosystem needs matter and energy to maintain its body, grow, develop, and to reproduce.

Organisms interact with each other also by the food they eat, establishing **trophic interactions** between them.

For an ecosystem to exist, matter and energy must move from one individual to another. Thus, **trophic levels** are established depending on how the organisms obtain matter and energy.

The three basic ways in which organisms get food are as ***producers***, ***consumers***, and ***decomposers***.

Ecosystems

Trophic interactions: trophic levels – producers

Producers are ***autotrophs*** which manufacture their own food, synthesizing organic matter from inorganic matter using ***photosynthesis***.

They are typically ***plants***, ***algae***, and ***photosynthetic bacteria***.

Image: Abrget47j
CC BY-SA 3.0

Ecosystems

Trophic interactions: trophic levels - consumers

Consumers are ***heterotrophs*** which cannot manufacture their own food and need to ***consume other organisms***. Within this trophic level, there are the following categories:

- **Primary consumers** are animals that eat producers (like plants). They are called ***herbivores***.
- **Secondary consumers** are animals that eat other animals. They are called ***carnivores***. ***Omnivores***, who feed on both plants and animals, can also be considered secondary consumers.

Image: Luis Miguel Bugallo Sánchez
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Image: Luca Galuzzi - www.galuzzi.it
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Ecosystems

Trophic interactions: trophic levels - decomposers

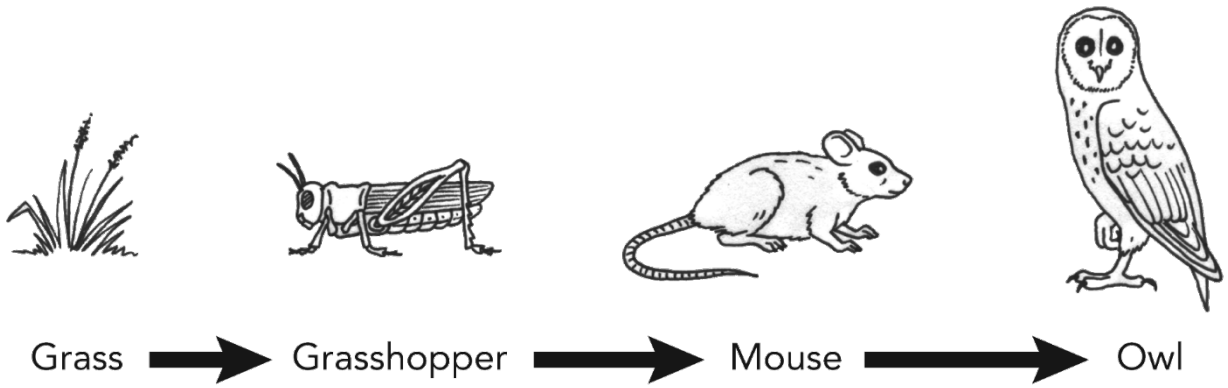
Decomposers are ***heterotrophs*** which feed on ***waste and dead matter*** breaking it down and releasing it again as energy and nutrients into the ecosystem for ***recycling***.

They are typically ***bacteria*** and ***fungi***.

Ecosystems

Trophic interactions: food chain

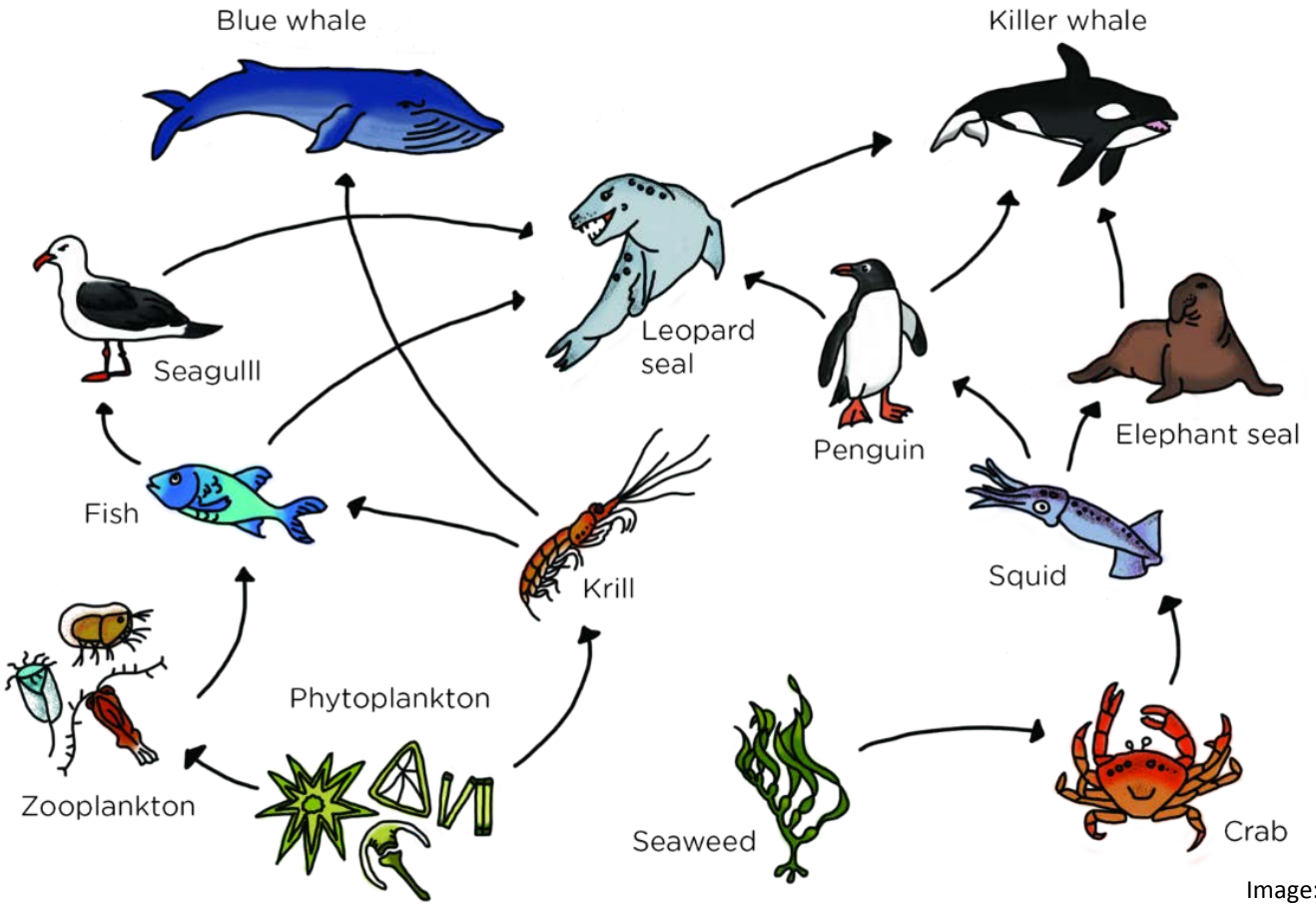
A **food chain** is a linear pathway which shows how the organisms are related with each other by the food they eat.



Ecosystems

Trophic interactions: food web

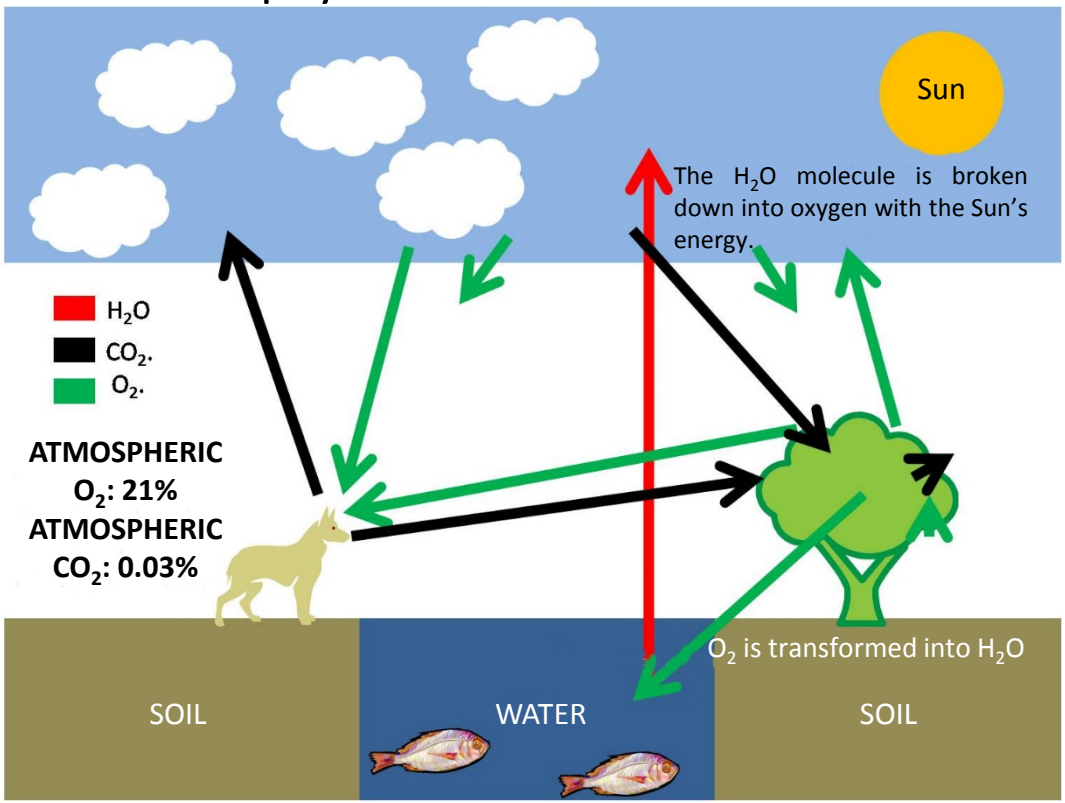
However, food chains are interconnected establishing a **food web**.



Ecosystems

Nutrient cycle

In every ecosystem there is a **nutrient cycle**, which is a perpetual movement and exchange of organic and inorganic matter (***nutrients***) from the physical environment into the living organisms and then recycled back into the physical environment.



Oxygen cycle.
Image: Danie1996 / A.R. Esteve
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Ecosystems

Nutrient cycle

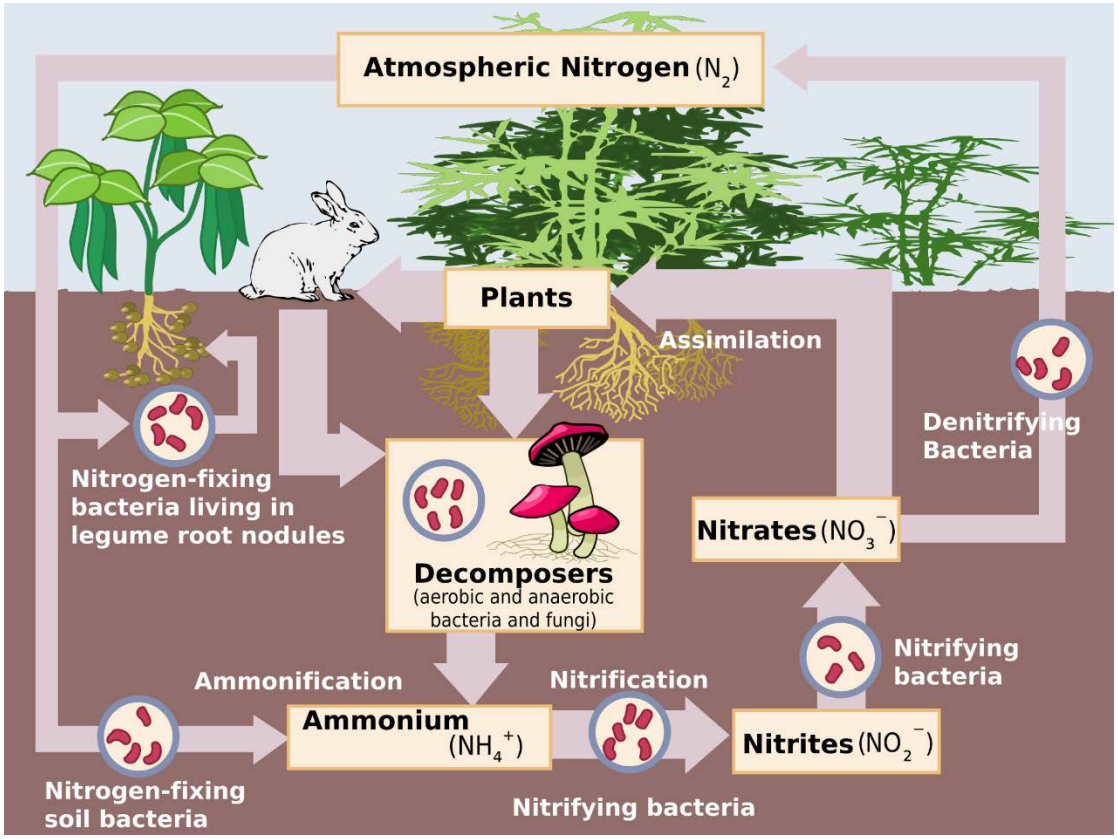
In every ecosystem there is a **nutrient cycle**, which is a perpetual movement and exchange of organic and inorganic matter (***nutrients***) from the physical environment into the living organisms and then recycled back into the physical environment.

- **Producers** synthesize ***organic matter*** (carbohydrates) from ***inorganic matter*** (water, salts, and CO_2) during ***photosynthesis*** using ***solar energy***.
- This organic matter will move from one **consumer** to another through the ***food chain/web***.
- The ***waste and dead matter*** from producers and consumers will be transformed by the **decomposers** into ***inorganic matter*** again.

Matter in nature is limited. However, the nutrient cycle allows the mineral nutrients to be continually recycled and used again and again.

Nutrient cycle

The main nutrient cycles are the ***water cycle*** (H_2O), the ***carbon cycle*** (CO_2), the ***oxygen cycle*** (O_2), the ***nitrogen cycle*** (N, N_2), and the ***phosphorus cycle*** (P).

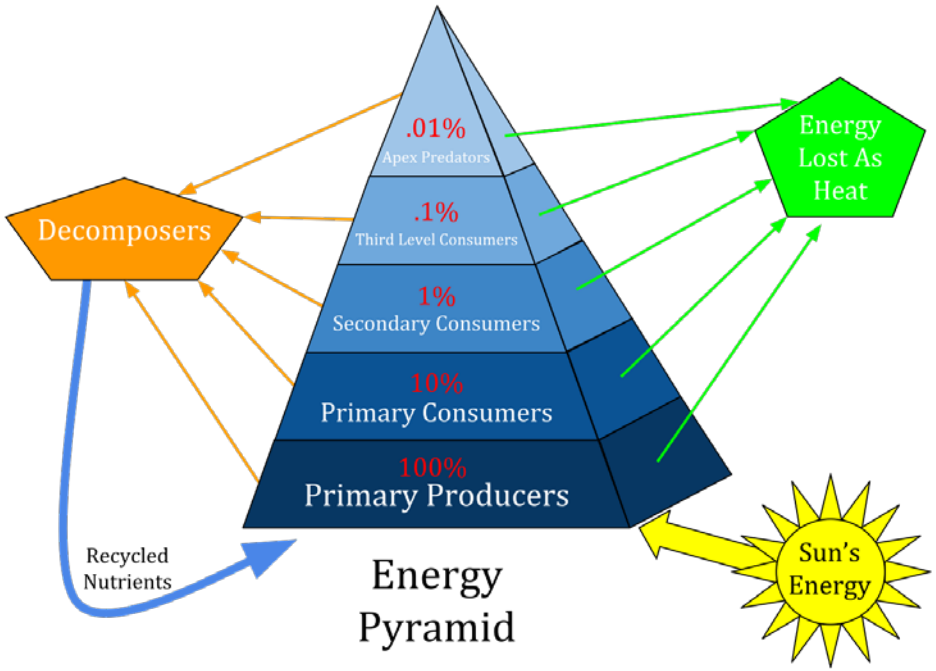


Nitrogen cycle.
Image: Johann Dréo

Ecosystems

Energy flow

In every ecosystem there is an **energy flow** through a food chain in an unidirectional and noncyclic pathway. However, each time the energy is passed on from trophic level to trophic level ***about 90% of the energy is lost***, mostly as ***heat*** into the environment.



This loss of energy limits typical food chains to only 4 - 6 links.

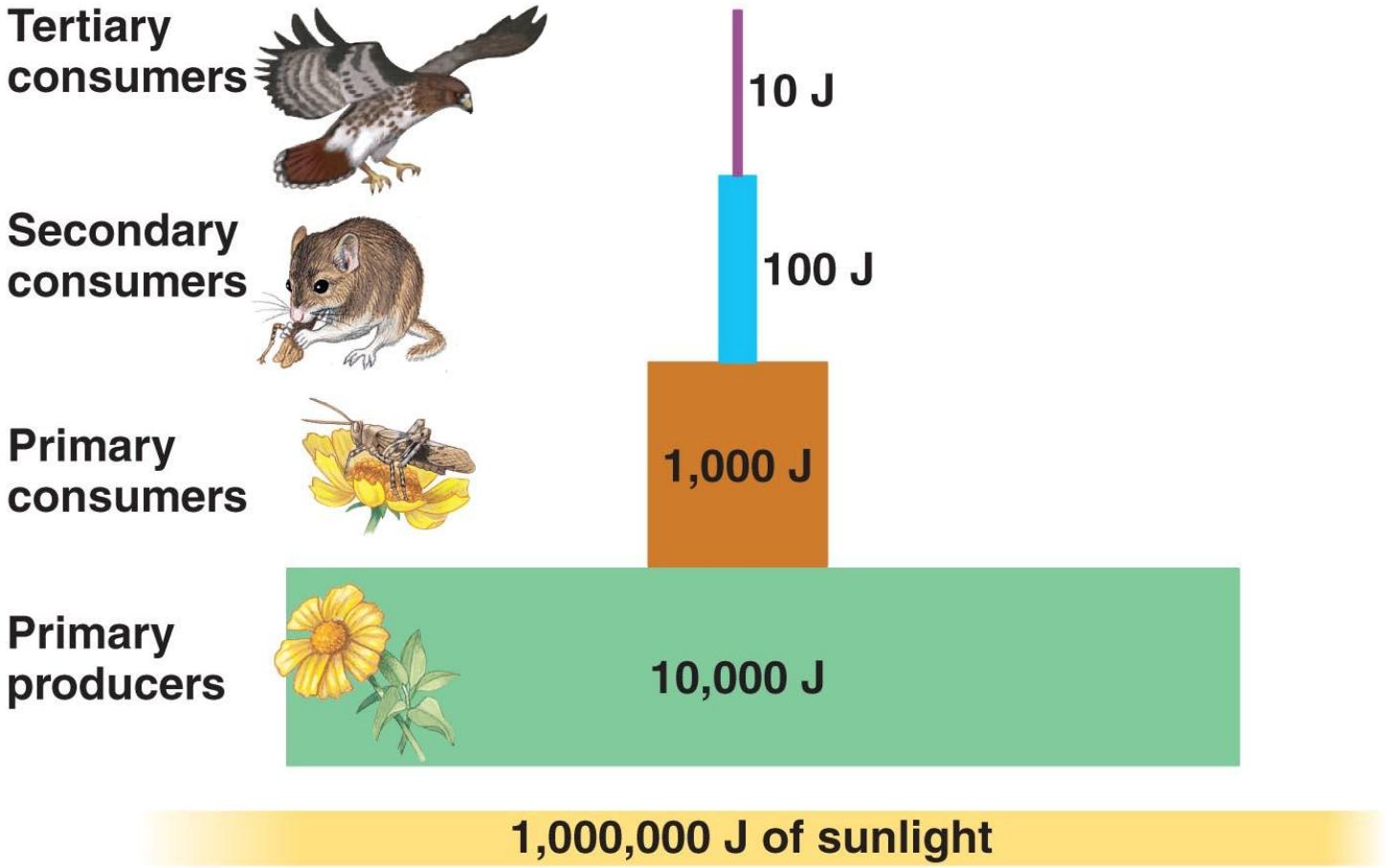
Ecosystems

Energy flow

- ***Solar energy*** is fixed by the **producers** (plants), who synthesize organic matter from inorganic using ***photosynthesis***.
- **Primary consumers** (***herbivores***) absorb about 10% of the stored energy in plants through ***digestion***, and transform it into the energy they need through ***respiration***. Part of this energy is converted to body ***heat***, which is lost from the system. **Secondary consumers** (***carnivores***) absorb about 10% of the stored energy in herbivores and transform it into the energy they need. Again, some energy is lost from the system as body heat. **Tertiary consumers** (***predators***) absorb about 10% of the stored energy in carnivores, some is transformed into the energy they need and some is lost as body heat.
- **Decomposers** break down the organic matter of the consumers and release ***nutrients*** into the soil.

Ecosystems

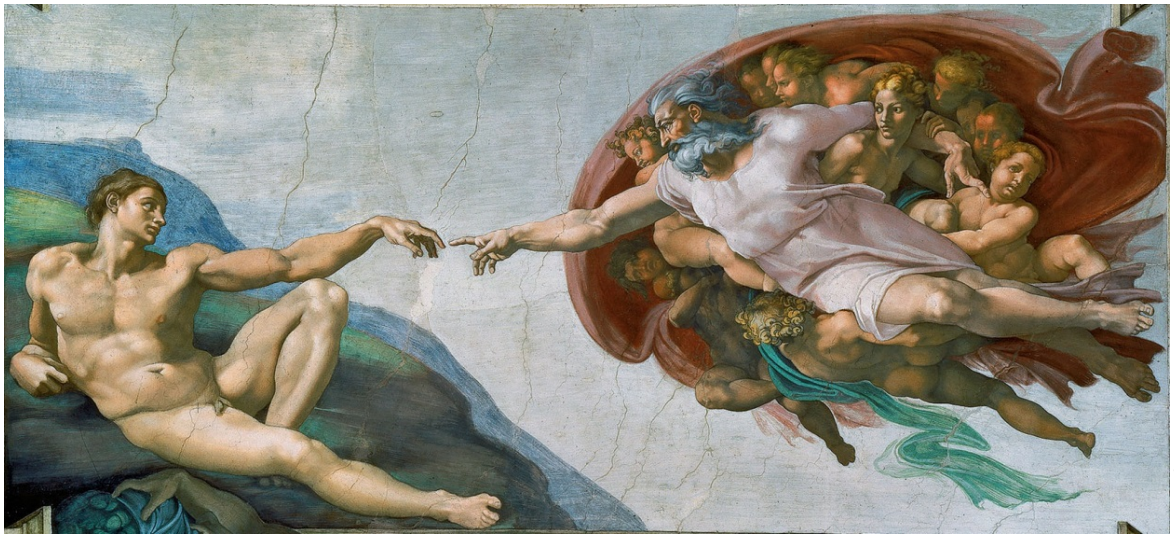
Energy flow



Origin and evolution of organisms

The origin of life

There have always been explanations about the origin of life on Earth that assume that a god or several gods "created" everything that exists.



The creation of Adam. Michelangelo. 1511.

Creationism is the religious ***belief*** that the universe and life originated from specific acts of divine creation.

Origin and evolution of organisms

The origin of life

Aristotle (384–322 BC) proposed the theory of ***spontaneous generation***.

For many centuries, it was thought that certain forms of life could arise from non-living matter such as dust, water, dead flesh, etc., without needing to descent from similar organisms.

This idea was based on common observations: worms arise from mud, maggots and flies from decaying flesh, mice from dirty hay, etc.

Origin and evolution of organisms

The origin of life

Francesco Redi (1626–1697) was the first person to challenge the theory of spontaneous generation.

Redi wanted to show that ***maggots in the decaying flesh come from eggs of flies, but not from the decaying flesh***.

Origin and evolution of organisms

The origin of life

Redi put chunks of meat in three jars: one was open, one was covered with fine gauze so that only air could get into it, and the third was sealed. After several days, he saw maggots appear in the open jar, but not in the covered jars, since flies could only enter the uncovered jar. Redi also captured the maggots and waiting for them to metamorphose, becoming flies.

Therefore, Redi concluded that ***the maggots came from eggs of flies, but not from the rotting meat***.

Omne vivum ex vivo

All life comes from life

Origin and evolution of organisms

The origin of life

Antonie van Leeuwenhoek (1632–1723) was one of the first people to observe tiny forms of life (***microorganisms***) using microscopes of his own design.

He also studied red blood cells of many animals, spermatozoa, the anatomy of many insects (bees, flies, fleas, bedbugs or silkworms), the structure of the leaves of plants, etc. Therefore, van Leeuwenhoek is commonly known as the ***"father of microbiology"***.

He was against the theory of spontaneous generation.

Origin and evolution of organisms

The origin of life

Louis Pasteur (1822–1895) disproved spontaneous generation by performing several experiments.

Pasteur demonstrated that ***organisms do not spontaneously appear, they come from other organisms***.

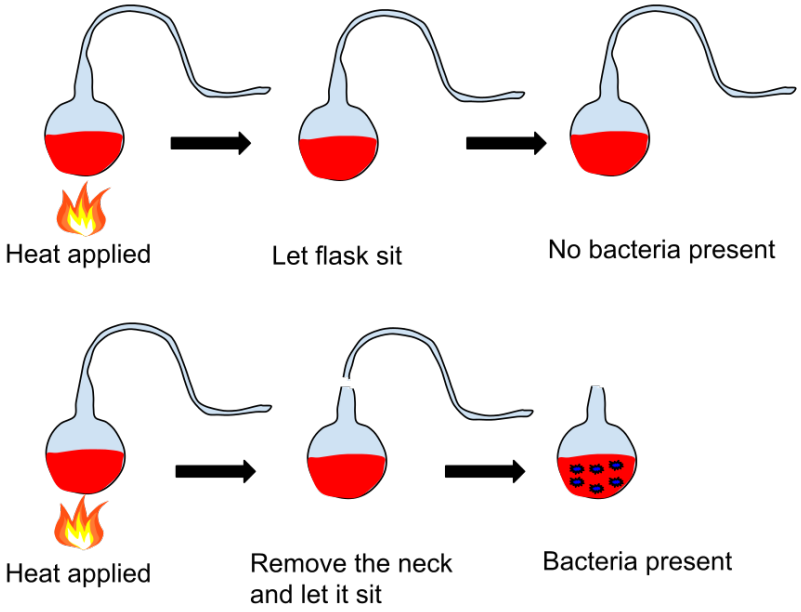
His discoveries provided direct support for the ***germ theory of disease***, which states that many diseases are caused by microorganisms.

Pasteur made remarkable breakthroughs in the causes and prevention of diseases, saving many lives ever since.

Origin and evolution of organisms

The origin of life

Pasteur placed boiled broth in two swan neck flasks, which had been previously sterilized. He let both flasks sit: one with the swan neck and the other without it. After several days, organisms had grown in the broth in the open flask. However, in the swan neck flask nothing had grown in it since no organisms could enter and contaminate the flask due to its swan neck.

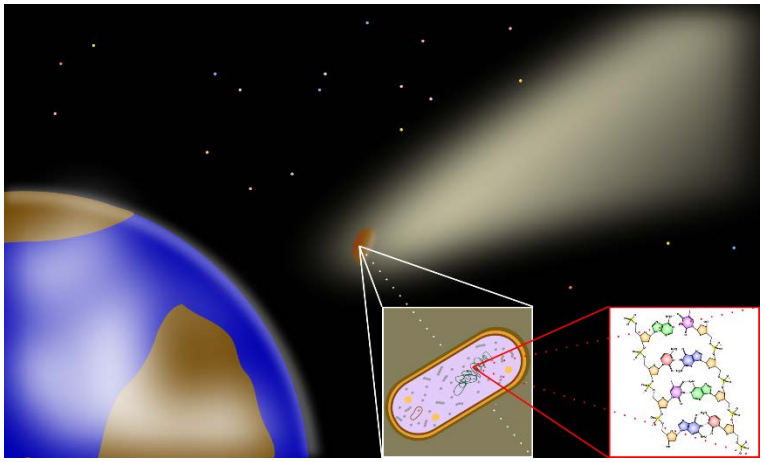


Origin and evolution of organisms

The origin of life

How did life on Earth begin?

Panspermia (from Ancient Greek *"pan"*, meaning *"all"*, and *"sperma"*, meaning *"seed"*) is a ***hypothesis*** which proposes that life could have originated anywhere in the universe reaching Earth in meteoroids, comets, space dust, etc.



Some studies suggest the existence of bacteria and precursor molecules to life which can survive in outer space.

However, ***this hypothesis does not address how life began***.

Origin and evolution of organisms

The origin of life

Currently, the generally accepted theory (**chemosynthetic theory**) that explains the ***origin of life*** is based on the hypotheses proposed by **Alexander Oparin** (1894–1980) and **John B. S. Haldane** (1892–1964) in 1924.

Origin and evolution of organisms

The origin of life

When Earth formed 4 500 million years ago, the heavier elements formed the planet's solid surface and interior, while the lighter ones formed the Earth's ***primitive atmosphere***.

The ***gases*** of this primitive atmosphere (methane, ammonia, hydrogen, and water vapor) were exposed to strong electric discharges (***lightning***) and intense ***UV solar radiation***, which made these gases to react forming the ***first organic molecules*** (*e.g., amino acids, simple carbohydrates, etc.*).

As the Earth cooled, the atmosphere's water vapor condensed forming clouds. ***Rain*** accumulated these organic molecules in the primitive oceans that were formed.

Primitive oceans were hot, which aided the simple organic molecules to react forming more ***complex organic molecules*** (*e.g., nucleic acids, proteins, etc.*). These oceans rich in organic molecules are called **primordial soup**.

Origin and evolution of organisms

The origin of life

Some of these complex organic molecules would combine in more complex ways forming aggregates of molecules (**coacervates**), which were not yet cells.

At some point, some complex organic molecule was able to ***self-replicate***, i.e., to make copies of itself, using other molecules in the primordial soup.

The first cells, which evolved from coacervates and exchanged matter and energy with their environment, were ***heterotrophic prokaryotes***, i.e., they fed on molecules from the primordial soup. Besides, since the Earth's atmosphere and oceans contained almost no oxygen, they were ***anaerobes*** (i.e., they did not use oxygen in their respiration to obtain energy).

Origin and evolution of organisms

The origin of life

When food became scarce, some cells became self-sufficient and became ***autotrophs***. This is how the first photosynthetic algae arose.

The oxygen produced during ***photosynthesis*** started to accumulate in the atmosphere. This oxygen-rich atmosphere aided the appearance of ***aerobic organisms***, which use oxygen in their respiration to obtain energy.

The structure of cells also evolved, and thus those with a nucleus (***eukaryotes***) arose.

At the same time, ozone started to be created from oxygen by UV solar radiation and to accumulate in the Earth's stratosphere forming the so-called ***ozone layer***, which protects the Earth's organisms by absorbing most of the Sun's UV radiation. The ozone layer allowed life to come out of the water and colonize the land.

Origin and evolution of organisms

The origin of life

In 1953, **Stanley Miller** (1930–2007) and **Harold C. Urey** (1893–1981) performed an experiment that supported the theory of a primordial soup, i.e., that organic molecules needed for organisms to develop could have spontaneously formed from inorganic precursors under the conditions on primitive Earth.

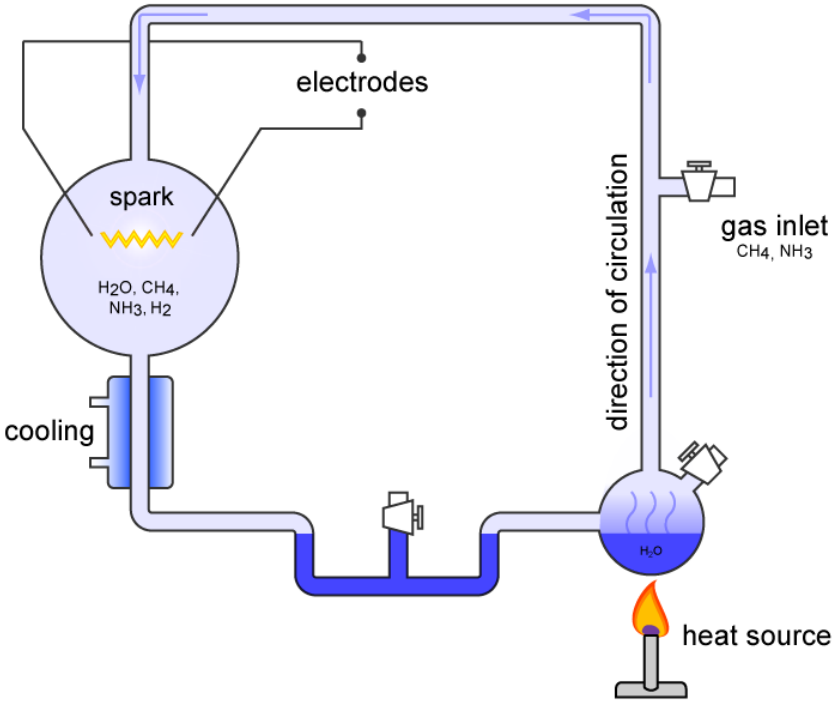


Image: Ggenellina / Carny
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Origin and evolution of organisms

The origin of life

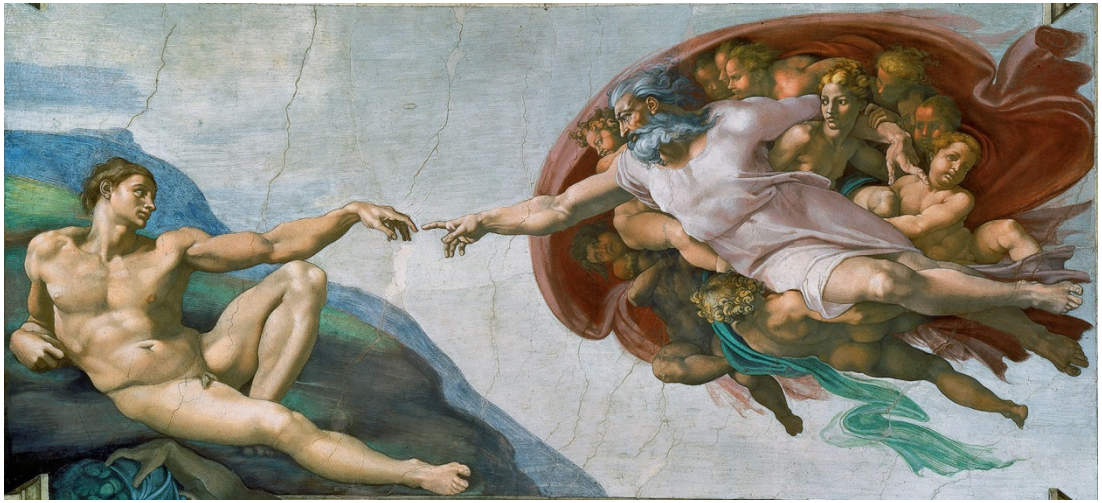
Miller and Urey used a custom-built glass apparatus to ***simulate the conditions of the primitive Earth's atmosphere and oceans***. They introduced liquid water in the smaller flask and heated it in order to obtain water vapor, which was introduced into the larger flask. Inside the larger flask was a mixture of gases (methane, ammonia, and hydrogen). Electrical sparks were delivered to the water vapor and mixture of gases to simulate lightning. This simulated atmosphere was cooled again so that the water vapor condensed and was collected in a U-shaped trap at the bottom of the apparatus.

After allowing the experiment to run for a week, the contents in the flask were visibly transformed: the liquid had turned a turbid, reddish color. When Miller and Urey analyzed the contents of this liquid, they found that several ***organic amino acids had formed*** spontaneously from inorganic raw materials.

Origin and evolution of organisms

Evolution: Pre-Darwinian theories

Fixism is the non-scientific theory that states that ***organisms do not change*** and that ***the species alive today are identical to those of the past***.



The creation of Adam.
Michelangelo. 1511.

Origin and evolution of organisms

Evolution: Pre-Darwinian theories

How can fixism explain fossil discoveries of extinct species?

Georges Cuvier (1769–1832) popularized **catastrophism**, which stated that ***species are immutable and natural catastrophes cause some species to become extinct*** creating opportunities for the advancement of other existing species.

Cuvier proposed that ***fossils*** were the result of the ***extinction in biblical catastrophes*** of some of the species created by God.

Noah's ark.
Edward Hicks. 1846.

Origin and evolution of organisms

Evolution: Pre-Darwinian theories - Lamarckism

In 1809, **Jean-Baptiste Lamarck** (1744–1829) proposed the ***first theory of evolution***, which stated that ***organisms*** had not been created and were not immutable, but ***had evolved from simpler forms of life***.

Origin and evolution of organisms

Evolution: Pre-Darwinian theories - Lamarckism

Lamarckism is based on:

- **The complexifying force.** Organisms have an innate tendency to evolve towards an increasing biological complexity, i.e., to become more complex, in order to become more adapted to their environment.
- **The adaptive force.** A more frequent and continuous use of any organ gradually strengthens, develops and enlarges it; while the permanent disuse of any organ progressively weakens and deteriorates it, until it finally disappears.
- **Inheritance of acquired characteristics.** An organism can pass on characteristics that it has acquired during its lifetime to its offspring.

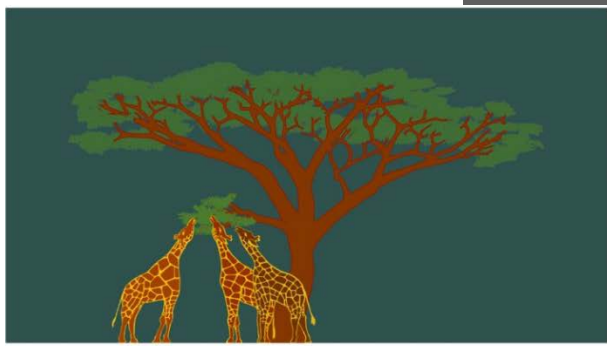
Origin and evolution of organisms

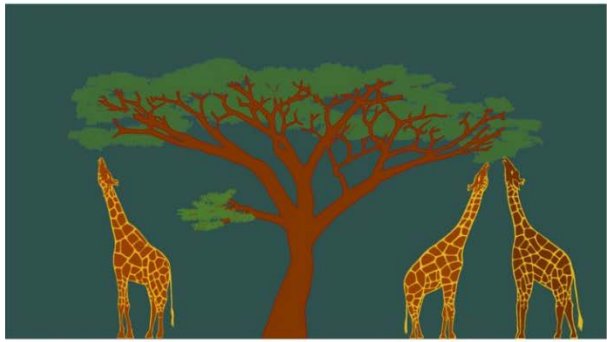
Evolution: Pre-Darwinian theories - Lamarckism

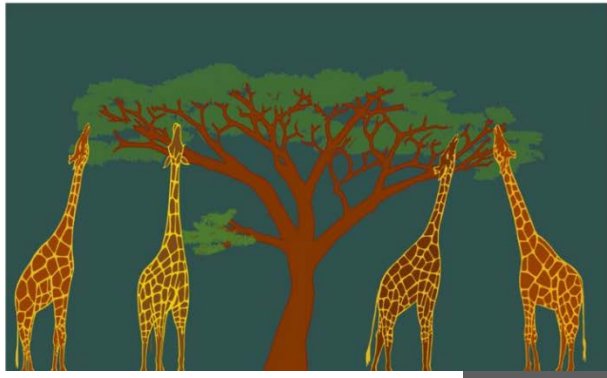
Example:

Primitive giraffes, which had shorter necks, frequently stretched their necks to reach food in the highest branches of the trees, making their necks longer because they were used a lot.

Their offspring would inherit the longer necks, and continued stretching would make it even longer over several generations.







Origin and evolution of organisms

Evolution: Pre-Darwinian theories - Lamarckism

Nowadays, it is known that an organism's ***acquired characteristics*** to become more adapted to its environment can not be registered in its genes, and therefore they ***can not be inherited*** by its offspring.

Examples: the musculature of athletes or bodybuilders, body piercing, etc.

Image: Erik van Leeuwen
http://www.erki.nl/
GFDL

Image: William Rafti
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Origin and evolution of organisms

Evolution: Theory of evolution by natural selection

At the end of the 19th century, **Charles Darwin** (1809–1882) and **Alfred Wallace** (1823–1913) simultaneously developed a similar theory: ***all species have descended over time from common ancestors through a process called natural selection***.

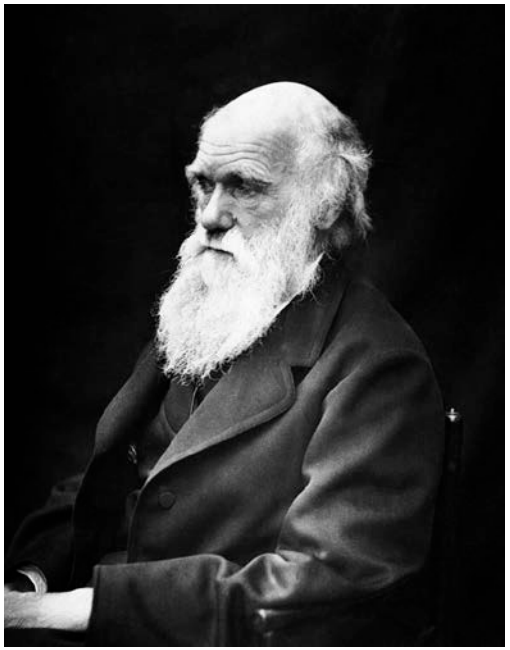

Image: J. Cameron

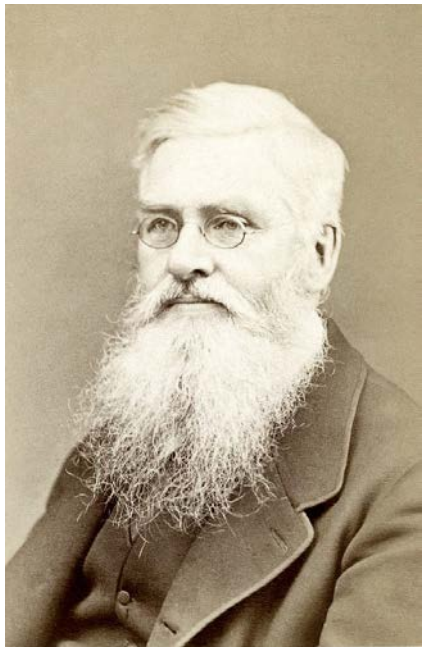

Image: Maull & Fox photographers
Bibliothèque nationale de France

Origin and evolution of organisms

Evolution: Theory of evolution by natural selection

The **theory of evolution by natural selection** is based on:

- ***More individuals are produced each generation than can survive.*** Organisms can produce more offspring than their environment can support. Therefore, individuals must compete for limited resources.
- ***Individuals in a species show a wide range of variation***. The offspring in any generation will be slightly different from one another in their traits (color, size, shape, etc.), and these ***traits are often heritable***.
- In a population, ***individuals with heritable traits that best adapt them to their environment are more likely to survive and reproduce more***. Thus, these traits will become more common in next generations.
- ***Given enough time,*** the population will become adapted to its environment and ***a new species will form***.

Origin and evolution of organisms

Evolution: Theory of evolution by natural selection

Darwin got a naturalist position on the ship ***Beagle***, in which he made a five-year voyage around the world which provided him the ideas that led to his **theory of evolution by natural selection**.

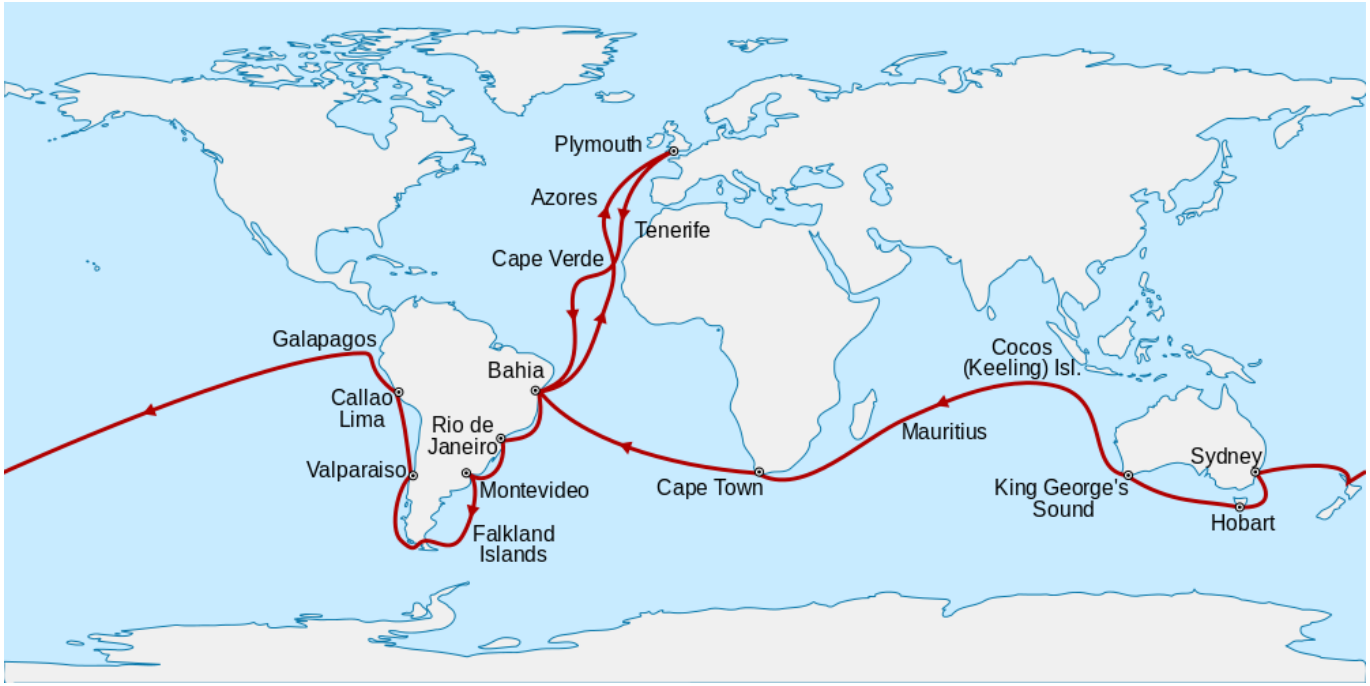

Image: © Sémhur / Wikimedia Commons
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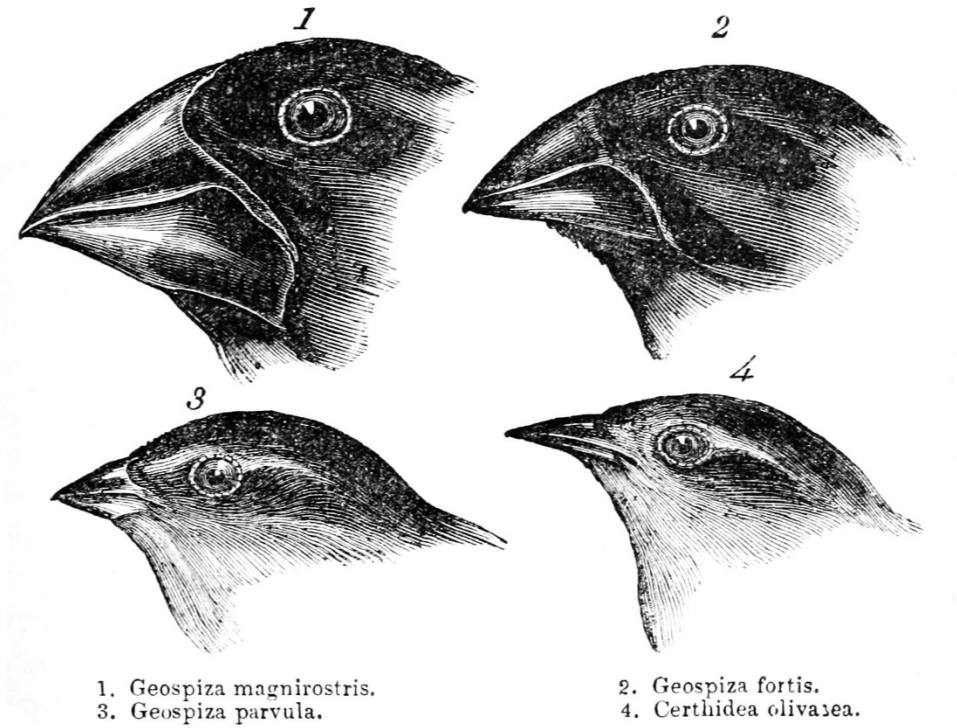
Origin and evolution of organisms

Evolution: Theory of evolution by natural selection

Darwin found 13 different species of ***finches*** on the ***Galápagos Islands***. These species were similar, but differed in beak size and beak depth, which were adapted to the local food conditions.



Origin and evolution of organisms

Evolution: Modern synthesis

In the 20th century, the **modern synthesis** connected Darwin's ***theory of evolution by natural selection*** with Mendel's ideas about ***genetics***.

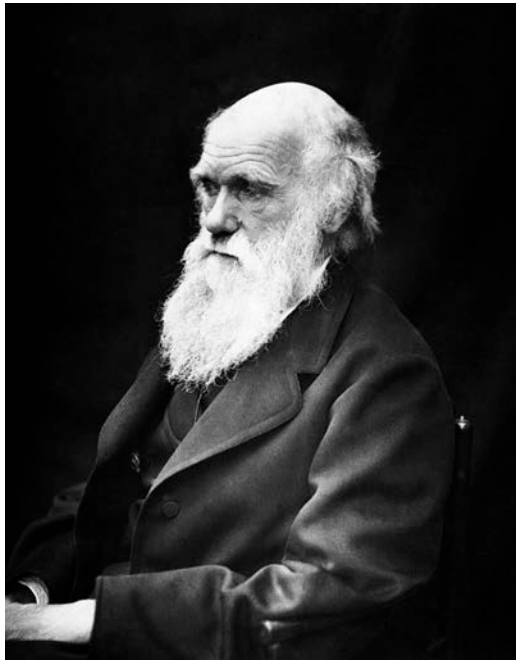


Image: J. Cameron

Theory of evolution by natural selection

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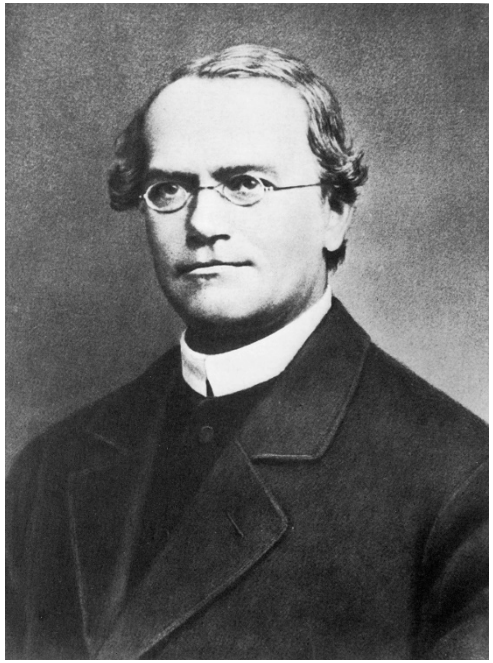


Mendelian genetics

→ **Modern synthesis**

Origin and evolution of organisms

Evolution: Modern synthesis

The modern synthesis is based on:

- **Genetic variation in populations** arises through random ***mutations*** (changes in genetic information), ***genetic recombination*** (reorganization of genetic information), and migrations between populations (***gene flow***).
- **Populations evolve by changes in the frequencies of genes** between one generation and another as a result of ***natural selection*** (some traits make it more likely for an organism to survive and reproduce) and ***genetic drift*** (some individuals may, just by chance, leave behind a few more descendents than other individuals).
- When populations are reproductively isolated by geographic barriers, they evolve to become distinct species (**speciation**).

Origin and evolution of organisms

Evolution: Modern synthesis

Example: ***Biston betularia*** *(a.k.a. peppered moth)*

Before the Industrial Revolution in England, the peppered moth was typically white, and black ones were rare.

During the Industrial Revolution, the countryside became blanketed with soot from the coal-burning factories, and the trees became darkened. This led to the death of most of the white moths due to bird predation and an increase of the population of the black moths since they camouflaged very well on the blackened trees (98% of the peppered moths in Manchester were black in 1895).

Since then, with improved environmental standards, white moths have again become common.

Origin and evolution of organisms

Evidence for evolution

There is overwhelming ***evidence that supports the idea that life has existed for millions of years and has changed over time***:

- fossils
- biogeography
- anatomy
- embryology
- molecular biology

Origin and evolution of organisms

Evidence for evolution: fossils

Fossils show how much or how little organisms have changed over time.

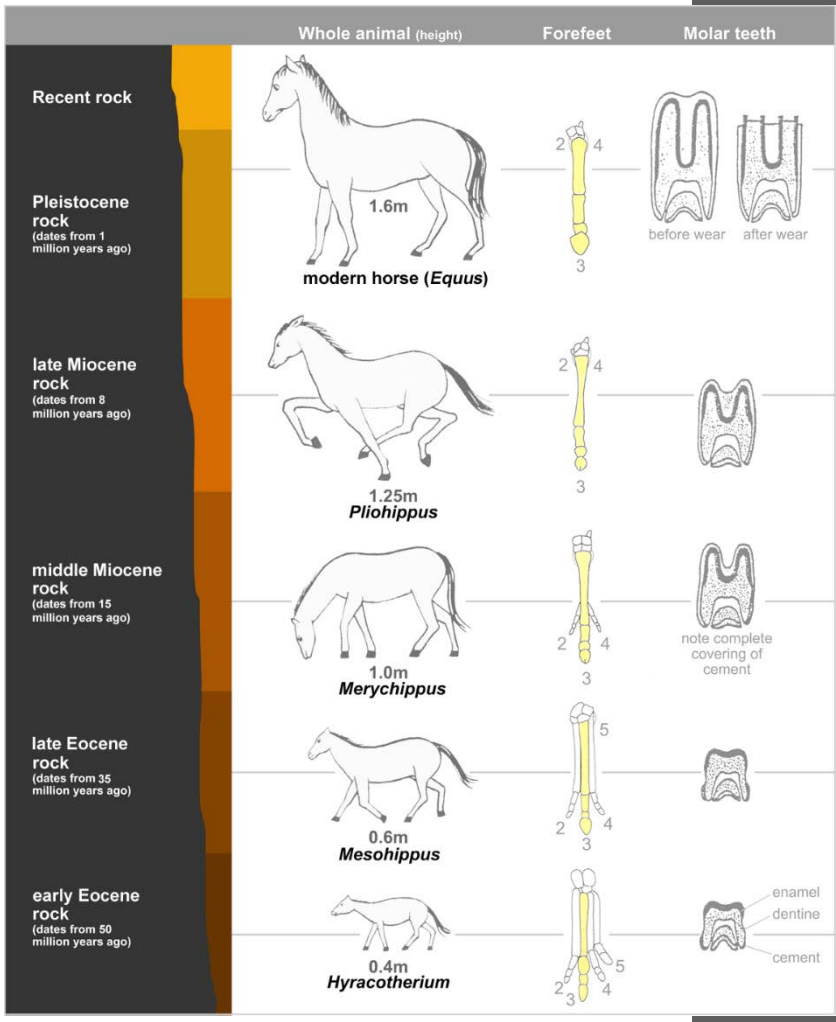
The fossil record provides evidence for evolution by revealing the features of an ancestor for comparison against living descendants.

Origin and evolution of organisms

Evidence for evolution: fossils

There are **series of fossils** that allow scientists to reconstruct the evolutionary lineage of present-day species and to know how the progression between species was.

*Example: the **evolution of the horse** from small multi-toed creatures to large single-toed animals.*



Origin and evolution of organisms

Evidence for evolution: fossils

There are fossilized remains of an organism that shows the intermediate states between an ancestral form and that of its descendants (**transitional form**).

*Example: **Archeopteryx** is considered a transitional form between reptiles and birds. It had broad wings, a jaw with sharp teeth, fingers with claws, a long bony tail, and feathers.*

Origin and evolution of organisms

Evidence for evolution: fossils

Some organisms have hardly evolved, remaining unchanged over millions of years.

Examples: ***horseshoe crab***, ***ginkgo***, ***platypus***, *etc.*

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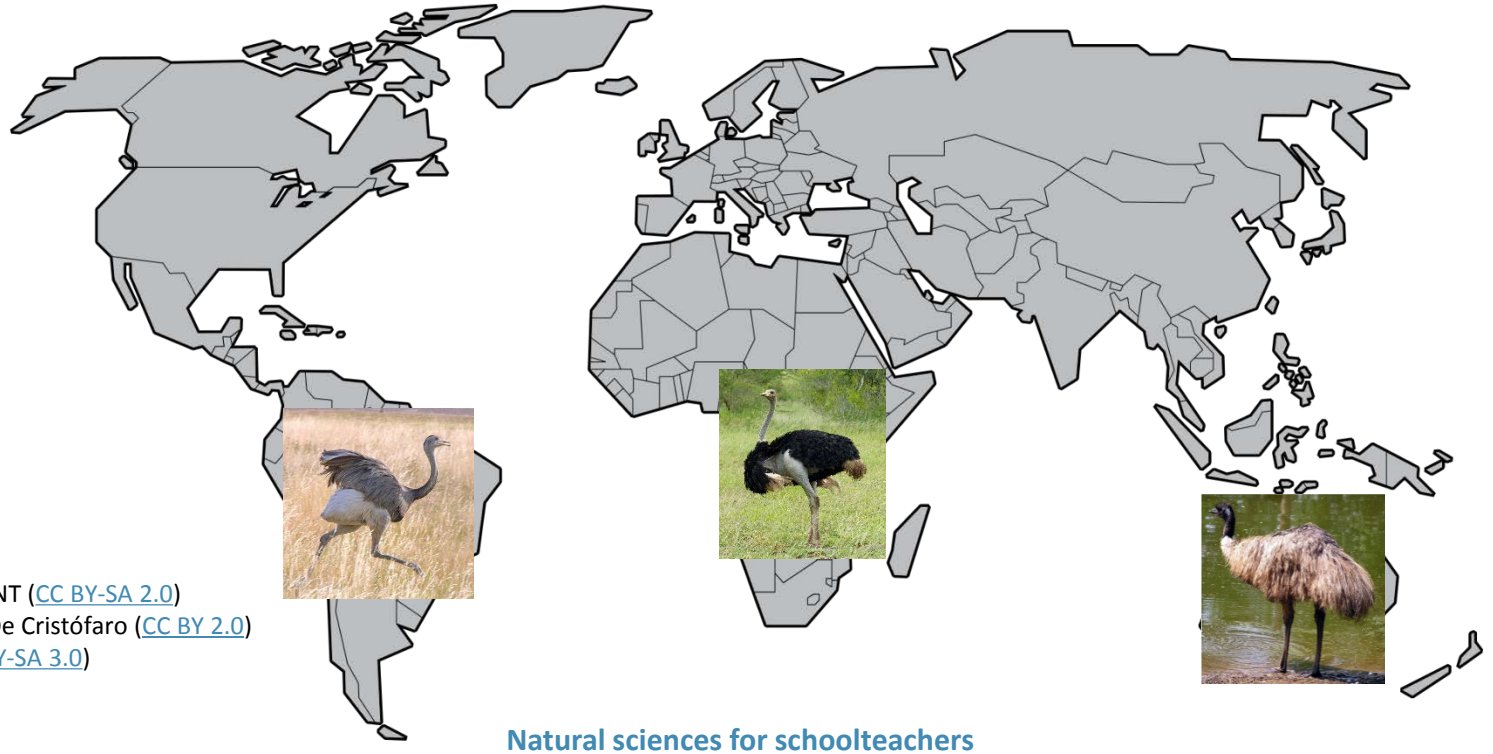
These organisms allow scientists to know how some extinct organisms, from which only fossils remain, looked like.

Origin and evolution of organisms

Evidence for evolution: biogeography

The **geographic distribution of organisms** on Earth follows patterns that are best explained by evolution, in combination with the movement of tectonic plates over geological time.

Example: geographic distribution of large birds: ***ostrich*** *in Africa,* ***rhea*** *in South America and* ***emu*** *in Australia.*



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Origin and evolution of organisms

Evidence for evolution: anatomy

The study of similarities and differences in the **anatomy** of different species provides information about the evolution of species and the relationship between them.

Two major concepts of comparative anatomy are:

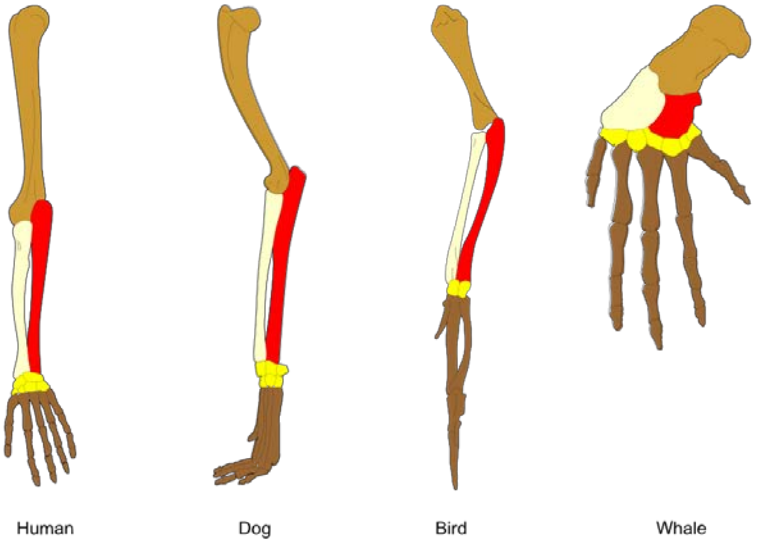
- **Homologous structures**, which are similar in different species because they have evolved from a common ancestor. They may or may not perform the same function. *Example: the forelimb structure shared by vertebrates.*
- **Analogous structures**, which are similar in different organisms because they evolved in a similar environment, but not from a common ancestor. They usually serve the same or similar purposes. *Example: the wings of insects and birds.*

Origin and evolution of organisms

Evidence for evolution: anatomy

Example:

*The **forelimbs of vertebrates** are **homologous structures** because, although they do not have a similar function, all are derived from the same ancestral tetrapod structure.*



*Homologous structures indicate a shared ancestry in different species, and the differences between these species are due to a process of **divergent evolution**.*

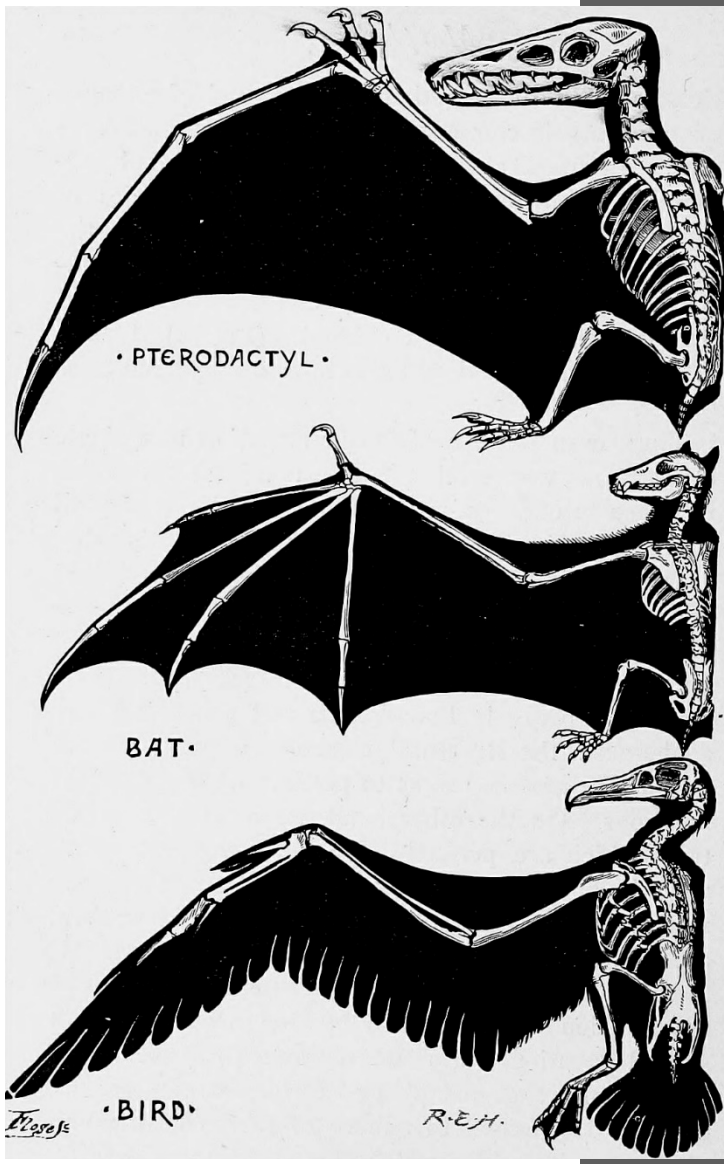
Origin and evolution of organisms

Evidence for evolution: anatomy

Example:

*The **wings of insects and birds** are **analogous structures** because they have a similar function (i.e., support flight), although they are not derived from structures present in a common ancestor.*

*Analogous structures are the result of the independent evolution of similar features in species of different lineages (**convergent evolution**).*



Origin and evolution of organisms

Evidence for evolution: anatomy

Moreover, **vestigial structures** are degenerate, atrophied or rudimentary organs that have lost much or all of their original function through evolution.

Example:

*The **undeveloped hind legs** of **whales** are remnants of their land-living ancestors' legs.*

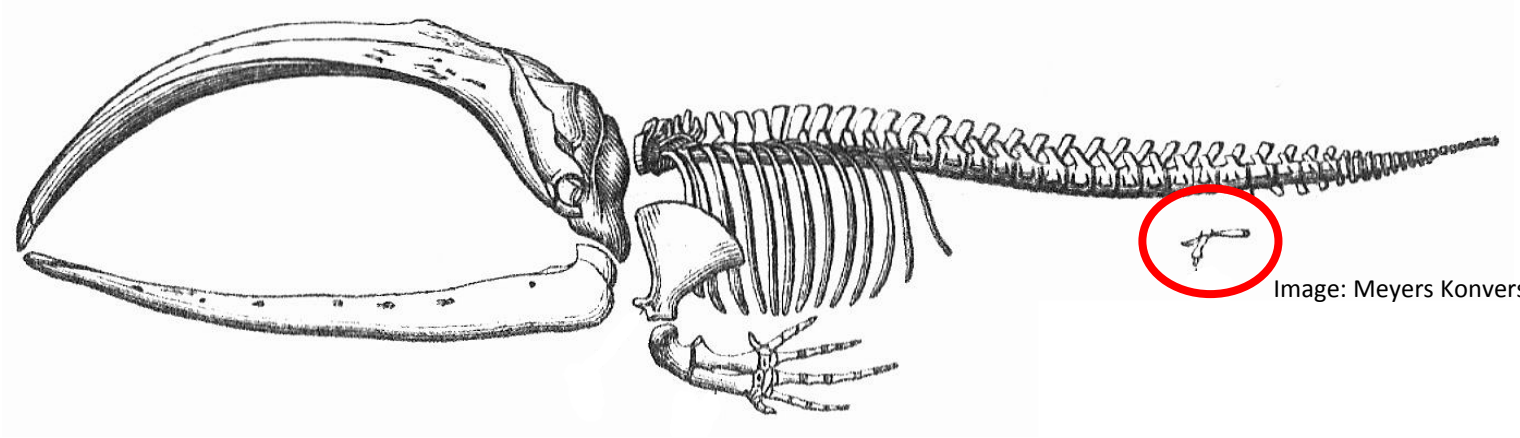


Image: Meyers Konversionlexikon

Origin and evolution of organisms

Evidence for evolution: embryology

The study of **embryonic development** of different species of vertebrates also provides information about the evolution of species and the relationship between them.

Example:

*Some structures (e.g., segments, limbs) are usually **identical in the embryos of different species** (e.g., fish, birds, and mammals), but they are **quite different and specialized in the adult forms**.*

The only possible scientific explanation for this is that the same embryonic development has been transmitted from a common ancestor to all these species.

Origin and evolution of organisms

Evidence for evolution: molecular biology

The study of similarities and differences in the **biological molecules *(e.g., proteins, nucleic acids, etc.)*** of different species provides information about shared evolutionary ancestry.

Example: Differences between the DNA of great apes and humans.

SPECIES	DNA DIFFERENCES (%)
human – gorilla	1.4
human – chimpanzee	1.2
gorilla – chimpanzee	1.2
human – orangutan	2.4
gorilla – orangutan	2.4
chimpanzee – orangutan	1.8

The more similar the biological molecules of two species are, the fewer evolutionary differences they have.